ORR'S

CIRCLE OF THE SCIENCES:

A SERIES OF TREATISES ON THE PRINCIPLES OF SCIENCE,
WITH THEIR APPLICATION TO PRACTICAL PURSUITS.

VOLUME IV.

INORGANIC NATURE—VOL.

GEOLOGY AND PHYSICAL GEOGRAPHY—PROF. ANSTED, M.A., F.R.S.
MINERALOGY AND CRYSTALLOGRAPHY—PROF. TENNANT,
AND REV. W. MITCHELL, M.A.

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INTRODUCTORY NOTICE.

The following pages are intended to supply the student with a comprehensive account of the present condition and probable early history of the external crust of the earth, an elementary treatise on the science of Crystallography, and a systematic arrangement and description of the various Minerals found in nature.

The author of the treatise on Geology has already published both elementary and practical works on the subject; and to one of these he feels it right to refer, as it may seem not dissimilar to the present treatise in plan and treatment. The work alluded to ("Elementary Course of Geology, Mineralogy, and Physical Geography," London, 1850) is, however, in reality very unlike this, and adapted for a different purpose. It may either succeed or accompany this volume in the hands of the student, but cannot be substituted for it, being more technical, and in greater detail in the departments of Physical Geography and Descriptive Geology; while the Geological portion of the following pages will be found to abound in generalization,—theoretical, descriptive, and practical. As an instance, the Author may mention the distinct treatise on the application of Geological Knowledge to the Art of Landscape Painting, which forms a prominent part of the division entitled "*Practical Geology.*" The novelty of this subject, its great interest, and a due consideration of the many ways in which the observations of the Artist and the Geologist run parallel, form an ample apology for its insertion; and the mode in which the subject was received by the profession (when it formed the substance of a series of Lectures delivered a few years ago at the Suffolk Street Gallery, before the Society of British Artists) has induced the Author to bring it forward on the present occasion.

Many other practical applications of Geology have also been dwelt upon at considerable length, but these hardly require explanation. The subjects of Water Supply, Mineral Fuel, and Mining, come too frequently before every man engaged in active pursuits to be otherwise than interesting; and the space given to them, though considerable, bears no undue relation to their real importance.

It is only necessary to explain further, that the descriptive part of Geology, and the details of Palæontology, have been reduced to an outline, in order to admit of a fuller development of other divisions of the same great department of human knowledge.

The treatises on Crystallography and Mineralogy will, it is hoped, be found to contain all the information which can be required by a student wishing to master the elements of those sciences. The various forms of Crystals are referred to six great classes or systems; under each system will be found complete lists of all the minerals known to have assumed forms or faces belonging to it, together with the angular elements which determine their relation to their axes. Each form belonging to the system is then described; its mathematical properties discussed; simple geometrical constructions are given for modelling every variety which can occur in nature, as well as rules for representing them on paper, and laying down their poles on the sphere of projection or its map. This is followed by a list of all the species of the form which have been observed in the Mineral Kingdom, the symbols used by various authors for their description, and their respective angles.

All the important formulæ for the calculations of the angles of Crystals are given, and these formulæ are solved for nearly every case which has been recorded in the best and most recent works on Mineralogy. Indeed it may be stated, with perfect propriety and truth, that this is the only treatise at all available to the student, in which the systems of Crystallography are treated in a manner suitable for the class or lecture room.

In the systematic description of the principal physical properties of Minerals, the chemical arrangement of the British Museum has been followed, as possessing great advantages for those who may avail themselves of the facilities afforded them in consulting one of the finest collections of Minerals in the world.

The student is thus presented with two distinct classifications of Minerals,—one in the Crystallography, according to the forms of their crystals, and the other following their chemical composition.

LONDON, *November*, 1855.

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PHYSICAL GEOGRAPHY AND GEOLOGY.

General Introduction.—The science of Geology, at the present day, is not by any means that collection of theoretical views and vague notions which it was supposed to be, and to some extent really was, a quarter of a century ago. Its facts are numerous, well arranged, and of an importance that cannot be questioned. The opinions held by its students are based upon various minute observations, and on analogies strictly philosophical. The reasonings from which its conclusions are drawn, are strictly inductive, and the results obtained are applicable to various practical purposes, and are second to none in importance.

It embraces also a wide range of knowledge, as well as application—Physical Geography, Chemistry, Mineralogy, Zoology, and Botany, being successively called on for their aid, while Agriculture, Architecture, Civil and Military Engineering, and Mining are all dependent on it for much essential assistance, and are becoming more so every day.

Geology is now generally understood to include all those departments of the various sciences of observation which help to explain or describe the actual condition of the earth's surface, and the various phases through which it has passed. It is thus at the same time a description and history of our globe; and although the mere descriptive part is recognised under a distinct name—Geography—yet is this term only understood generally as applying to the earth as the habitation of man, and with reference to the distribution and wants of the various families of the human race.

The past history of the earth, using this term in its most extended sense, neces-

sarily involves the consideration of various possibilities, about which much clever argument has been wasted, and much ill-feeling excited. The discussion of questions of this nature is, however, as unphilosophical as it is undesirable, for the duty of those who pursue science, and endeavour to render it useful to the general public, is clear and straightforward. They have to present facts as they appear, and describe nature as she presents herself. They may indeed suggest inferences, but they have nothing to do either with doubts or dogmas; and in all cases this simple statement of truth, as it is received, felt, and acted on, cannot be other than right and useful, from whatever direction it comes, or whatever difficulties may appear to be connected with its development.

Physical Geography.—One of the first subjects for consideration, in a treatise, however brief, on general Geology, must be the actual present condition of the earth. Without some knowledge of this, there is no foundation on which to build useful geological knowledge of any kind,—all is vague, uncertain, and shifting, and any deductions and conclusions as to former conditions or former changes, are almost certain to be false, or lead to unsound generalizations, unless founded on actual knowledge of the present state of the earth, and the changes that now go on owing to the operation of known causes.

We propose, then, in the present paper, to give such outline accounts of the surface and external crust of our globe, as may communicate reasonable and correct ideas as to its possible mode of formation. We shall, not, indeed, enter into detail, rather desiring to direct attention to the great sources of information, than pretending to offer new and unconsidered statements, but we hope to show that this department of science not only requires study, but fully repays any attention given to it.

The form of the earth is well known to be that of a slightly flattened sphere,—the pole, or imaginary line between the northern and southern extremities, being shorter than a line drawn through the centre to meet the equator at opposite points. The amount of flattening at each pole is about $13\frac{1}{6}$ miles, or in other words, the shorter diameter differs from the longer by $26\frac{1}{3}$ miles. As, however, the diameter of the earth is nearly 8000 miles, the difference is not more than equivalent to a flattening of one-sixteenth of an inch in the case of a three-foot globe, which would be altogether inappreciable by the eye. There is no reason to suppose that the extreme vertical distance between the top of the loftiest mountain and the deepest point of the ocean exceeds this comparatively small distance, nor is it possible for us even to attain a knowledge of the present state of the interior from actual observation to an extent at all equal to this. It is well to bear in mind these facts in speculating on the state of matter so far out of the range of our observation as the interior of the earth's crust must of necessity be.

The surface of the earth, which may be stated in round numbers to consist of two hundred millions of square miles, is somewhat irregular, though, as we have already seen, the proportionate amount of the irregularities is small. About three-fourths of the whole, being the lower or recessed portion, is covered with water, varying in depth from a few inches to ten miles; and the whole, both land and water, is covered with a film, probably about one hundred miles in thickness, of a peculiar gaseous compound, called by us air, or the atmosphere. This would be equivalent to about half an inch on the surface of a three foot globe. All known phenomena of light, heat, and electricity—all the vast and marvellous and complicated phenomena of vegetable and animal life—all the chemical changes connected with the distribution and production of mineral wealth—everything we know of or think of in the earth, or can conceive of as con-

nected in any way with ourselves, goes on within this narrow belt of a hundred miles above and below the level of the ocean, or the half inch above and below the general surface of a large common globe whose diameter is thirty-six inches. Some people have endeavoured to illustrate the condition and form of the earth more familiarly by referring to an orange, but the thinnest skin of even a large fruit would be more than equivalent to the whole of this 200 miles, and the irregularities on the smoothest skin would represent gigantic mountains, compared with which, the Andes and Himalayas are but mole-hills.

But comparisons and analogies are not always the best modes of obtaining ideas on subjects such as those we are considering, for there are many things that are important and real, in the phenomena of the earth's surface, though, when reduced by comparison with small objects, they appear insignificant. Thus, it is necessary to consider somewhat closely the varieties of form and distribution of land in large masses, groups of islands, and detached islands, the distribution of water, as well in the atmosphere as on land, and in the ocean; the way in which the land is distinguished into mountains, lofty plateaux, and low plains; the natural separation of the land into drainage areas; the existence of volcanoes and earthquakes, the phenomena of springs, both cold and thermal; and the peculiarities of climate in various parts of the earth. All these subjects are introductory to Geology, and together, they form the science of "Physical Geography."

The natural taste for fine scenery possessed by almost every one, whether with a cultivated intellect or in a state of nature, and the marvellous scenes presented to our contemplation in different parts of the world, must suggest some inquiry as to the cause of those varieties of the earth's surface, and changes in atmospheric condition, which are so charming to the eye and the intellect. Thus, for example, we find, in the cold and almost frozen regions of Iceland numerous jets of boiling water spouting into the air to a great height, lifting up large blocks of stone from beneath the earth's surface, and projecting them to an enormous height. In Switzerland, only a day's journey from the warm, sunny regions of Italy, vast rivers of ice pour down from lofty mountains, and spread destruction over the plains. In the great tropical plains of Mexico, some hundred square miles of country have been thrust upwards, and a hill of sixteen hundred feet formed in a short space of time, from which fire and ashes are vomited forth, accompanied by melted rock. In the cold seas, in both the northern and southern hemispheres, near the two poles of the earth, blue mountains of ice, loaded with vast fragments of rock, are every day broken off, and floated away, and conveyed by winds and currents to warmer waters, where they melt and deposit their load. On our own coasts, and in the south-western parts of our own island, huge rocks of granite are worn by the sea and the air into the most quaint and picturesque shapes. In the warm seas of the Eastern Archipelago, myriads of little insects are building solid and massive walls of rock, defying the power of the waves, and slowly but surely rising up from the bottom of the sea, and apparently increasing the quantity of solid matter of the earth. It is natural to inquire what is the meaning of all this, and what do these various and striking natural appearances teach us? In reply to such a query, it may be stated, with reference to our present subject, that the study of these grand phenomena—the true interpretation of the language which these facts speak—leads directly and immediately to a knowledge of the ancient history of the earth; or, in other words, it enables us to judge of and comprehend that progress of events by which the earth's crust has, in the due course of time, become elaborated in the form which we now see. The

making out this ancient history of the earth—the determination of what has been by the investigation of what is doing—the comparison of past results with present effects—these are the proper objects of the science of Geology; and rising out of the investigations into the structure of the earth's crust, there appear a multitude of strange and startling conclusions—a crowd of facts concerning the ancient inhabitants, as well as the ancient surface of our globe, which at first may confuse and puzzle us by their novelty and complication, but which all fall naturally into their places, when they are studied fairly and honestly, with a due reference to existing nature.

Geology is often looked upon too much as a detached science—standing apart from the rest—almost repulsive from its numerous unfamiliar expressions—overloaded with technicalities, and although interesting, almost too difficult to approach. But, like every science connected with natural history, Geology may be a source of great pleasure and true enjoyment at a very small expense of time or trouble; though, in order that it may be so, the links by which it is connected with other sciences must be perceived and understood. The enjoyment derived from travelling—from visiting beautiful scenery, whether at home or in distant countries—is at the present day familiar to almost every one; and even those countries we have not seen, have been so frequently and accurately described, that we may be said to know them almost equally well. This enjoyment is derived partly from direct observations, and partly from reflection and comparison, and when made a special object of study, involves a distinct science—that of Physical Geography—which, however, includes a large group of facts, equally important in themselves, and in their bearing on Geology. Just in the way by which a knowledge of flowers, of insects, of birds, or of beasts, gives a fresh subject of interest to the traveller, and sharpens his sense of what is beautiful in nature, so is it also with a knowledge of the various peculiarities of the earth's surface. Such knowledge may be regarded as the most extended form of natural history, and being based on what we observe, with regard to the present course of nature, it traces out and describes the changes and modifications that the surface of our planet is now undergoing, and hence enables us to determine other changes which it has undergone, from the earlier periods of its existence up to the present time.

In such a description is included, not only the history of mechanical changes, but of those also which have affected the animals and vegetables living on the earth, or in the waters of the sea. Vast and almost boundless as the subject is, when thus contemplated, there are yet salient points, landmarks, as it were, which characterize certain parts of the subject; and on these the attention, once directed, will readily become fixed. These, then, it is desirable to bring prominently forward in preparing a sketch of Geology, and they must be arranged in such order as to illustrate, as clearly as possible, the conclusions to be drawn from their consideration.

Physical Geography may be described as involving a general description of the earth's surface; not in regard to man in his political and social relations (which forms the subject-matter of Descriptive Geography), but with reference to all mutual relations of matter and vitality on the globe. It thus comprises a very large and important part of a universal knowledge of nature. It treats of the general conditions of matter in the universe, and the forces by which it is affected,—of the atmospheric veil which surrounds the globe, and the various appearances belonging to it, and their results,—of the vast ocean that covers so large a portion of the solid surface with an uniform fluid,—of the way in which the land is distributed, the disturbances and alterations to which it is subject, the mode in which it has been formed, and all the natural families of vege-

tables and animals that either exist upon it now, or have lived there in former times. No minute description of districts can answer this purpose—for what is required is, that we should recognise unity in a vast variety of phenomena, and by the exercise of thought, and the combination of observations, discern that which is constant through innumerable apparent changes.

The object of the present paper will be to place in order several groups of facts which seem adapted to illustrate the general method of nature in the constitution of our globe; and there is no question that such knowledge is interesting as well as useful, and ought to form part of the general information possessed by every person.

For this knowledge and studies of this kind do not merely involve the communication of facts, but also the habit of making the best use of those facts; and they even possess some of the uses of more abstruse studies in teaching us to think clearly—to separate that which is unimportant—to place statements and facts in the order of their relative importance, and thus to obtain a habit of arriving rapidly at just conclusions from good grounds. The natural sciences possess this advantage in no trifling degree, when studied properly and with reference to general views.

But together with this advantage, they possess also another, namely—that they appeal to the feelings and the imagination as well as to the intellect. Science seeks to determine facts, to develop principles, to discover laws. Philosophy strives to obtain vast generalities from these discovered fragments—to ascend from matter and its properties to the influences which affect them, and the superior and unseen powers at work around us. "The imagination seizes the facts and the theories, unites them by pleasing thought, appeals for truth to the most unthinking soul, and leads the reflective intellect to higher and higher exercises; it connects common phenomena with exalted ideas, and invests the human mind with the strength of truth."

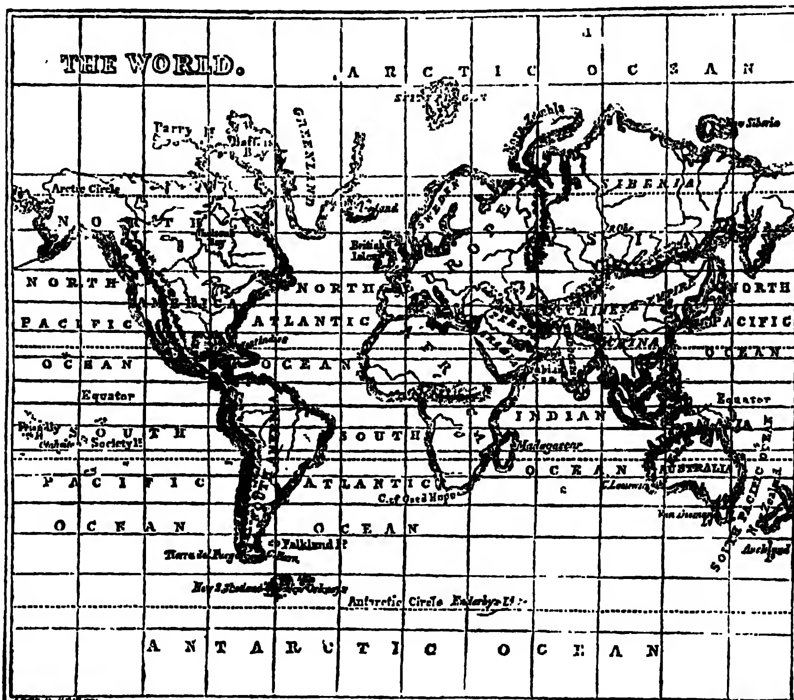
And if such is the case generally with science, it is so most strikingly with those sciences which are the basis of all,—the sciences of observation included in Physical Geography.

Materials of which the Earth is Formed.—As a first step in the investigation proposed as to the condition and appearance of the earth, let us call to mind a few of the principal facts concerning our planet. It has been already observed, that we live on the surface of a globe a little flattened at the poles and bulging at the equator. Three-fifths of this surface is covered with water, which reposes in the hollows or depressed portions sunk a certain distance below the general or mean level, whatever that may be.

No one looking at a globe or map (see page 6) will suppose for a moment that the distribution of land and water, and the relative levels of different parts of the surface, are points essential to the condition of the earth, either physically or with reference to its inhabitants. The land is oddly grouped in triangular areas. A great proportion of the whole land is in the northern hemisphere, and the bases of all the triangular areas are also directed northwards. In certain districts we find continents or large tracts of land,—in others islands or small tracts. The islands, too, are generally grouped, but sometimes isolated. These must all be considered as, in some sense, *accidental* phenomena, not necessarily existing as they now exist, and yet having a very important bearing on the temperature and many other conditions of the land. Besides the land and water, our globe is also completely encased by matter in a gaseous state. Now, a very slight acquaintance with Chemistry teaches that these three conditions of land, water, and air are only particular forms in which matter exists, owing partly to

temperature, and partly to the nature of the combination of a few elementary substances.

These elementary substances are hardly in any case met with in a simple state. Three of the so-called four elements—earth, air, and water—being compounds, and the fourth not in any sense an element, being merely a condition assumed during the process of decomposition and recombination of different elements. The actual nature and condition of the true elements is a subject for the chemist to discuss, and many of their



MAP OF THE WORLD.

properties we neither know nor perhaps ever can know, since we cannot meet with them in a state unaffected by those universal laws through whose agency the ultimate atoms arrange themselves into some definite form, or are left without definite shape, and spread abroad as gases or fluids; but, combined with one another in certain proportions, and under certain conditions, they are presented for our investigation. They mutually act upon one another, and, constituted as they are, they become the cause of perpetual movement and perpetual change. But this is owing to an agent of which we know far less than even of those darkly-comprehended ultimate atoms. Light, heat, and the various forms of electricity are, so far as we can discover, but different phenomena of one weightless, formless, non-material agent—ever present, ever active—distributed through infinite space; whose presence may, at any time, and in every place, be rendered instantly evident; and which is possibly brought into action by even the smallest con-

ceivable change in the mechanical position of each separate atom of created matter. This agent, affecting inorganic matter, which so surrounds us, without which we cannot conceive the existence of motion or the utility of matter, may almost be looked upon as representing *life* in inorganic nature, and as the mysterious channel by which the Author of nature has seen fit to exert his power in building together the whole material universe.

The particles of matter acted on by antagonist forces, separating them from one another, and attracting them towards one another, are thus collected into groups in the three conditions already alluded to.

The solid particles are, however, not so solid but that those which are fluid may detach them; the fluids are not so compact but that some portion is constantly being absorbed into the aërial; and, on the other hand, the aërial and the fluid are not so loosely compacted together but that they also form part of every solid, and of one another.

Two gases (oxygen and nitrogen), with the admixture of aqueous vapour, and a very small proportion of a solid element (carbon), form the atmosphere; two other gases (oxygen and hydrogen), one of them the lightest known, are mingled together, and unite in the liquid form of water; one of these (oxygen) is so abundantly present in that solid rocky matter which forms the greater part of the earth's crust, that half the weight of the whole mass is probably made up of it. The absence of heat, however, will reduce water into a solid, and the presence of heat will turn the heaviest and the most solid elements into air. We also find the action of electric forces frequently causing a re-arrangement of the particles in a solid mass—decomposing, recomposing, and in every way altering even those things which we may be inclined to think the least changeable and the most permanent.

The first lesson, then, that we have to learn in contemplating nature as she is, involves the overturning of all those ideas of stability and permanence which are so familiar to all. It was not in vain that Galileo said :—"E pur si muove." Not only does the earth move as a mass, but everything about her suffers change. In the air there is a constant absorption and distribution of fresh particles of matter, not only as the sun rises or sets, but as it varies its course during every moment of the day and night. All nature is, in this sense, animated; for the sea is never so still, the air is never so calm, but that these silent, invisible, but often very appreciable changes, go on. The whirlwind and the tempest are not the only, nor are they the most important, of these movements; since every breath of air, every ripple of the water, would disturb and disarrange the perfect equilibrium of these two so-called elements, did it ever exist, or had it ever existed.

It will readily be understood that the air and the water, acting, as they do, upon one another, and acted upon by changes of temperature, undergo constant change in their internal condition. The mist, the cloud, and the rain are indications of this, manifest to all, and every one is only too well aware that the air is clearer, or less clear, to-day than it was yesterday, and that every hour is marked by some fresh modification. And though not so immediately manifest, it is not at all less certain that every such change in the condition of the atmosphere, with respect to heat and moisture, produces also some result on the more solid framework of the earth.

The Atmosphere.—As one of the forms of matter on which much of the peculiar condition of the surface of our globe depends, it is then necessary to consider with some care the nature of that gaseous envelope which, in combination with water,

completely encloses us, and to which we shall be obliged to refer constantly in treating of the visible and solid crust.

Natural as it may seem to us at first that the earth should be provided with an atmosphere, there is no reason whatever for supposing that other planetary bodies are also so provided. Our satellite, the moon, is without any such covering, and it seems almost certain that there is upon its surface no aqueous vapour. With regard to some planets of our system, and those distant bodies whose very light is years and centuries in reaching us, we know nothing with respect to this condition; but we must look on all atmospheric phenomena as practically limited to our own planet.

When we consider, indeed, the use of the atmosphere, and its invariable relation with us to all forms of life, we shall find that, on this account, as for many other important reasons, the earth requires to be studied by itself; and that, in the conclusions we may draw with regard to its history, or the comparisons we may suggest with other bodies of our system, we must always keep within narrow limits, and not venture beyond reason in speculating concerning their sentient and organic beings. Inorganic nature appears to be everywhere governed by the same laws, and is so far invariable; but the relations of inorganic matter to living beings, may differ altogether in every case.

It is necessary to put prominently forward the fact of this isolation of our planet with regard to the history of its modifications and their bearing on the phenomena of life. A difference, as great as is conceivable, may exist in this respect consistently with the perfect uniformity of nature's laws. We are too apt to dwell upon analogies and resemblances, as well as differences, in minute and non-essential matters, forgetting that the true resemblance and difference must be sought for in the law, not the operation of the law. In nature, indeed, we find little mere repetition, and yet we see everywhere around us such perfect harmony, that, with our limited faculties, we are inclined always to expect identity.

Let us now come at once to the consideration of our atmosphere and atmospheric phenomena. Let us endeavour to learn what it is—what it does—what it prevents. Let us consider how it acts, and how far it is connected with the conditions of organic existence.

Air is a mixture composed of about one part of oxygen gas with four parts of nitrogen; but the atmosphere also includes, under ordinary circumstances, a small quantity of carbonic acid (about one part in a thousand), and a considerable proportion of aqueous vapour.

The following may be taken as representing the composition of a thousand parts of dry air at ordinary temperatures:—

Oxygen	210·0
Nitrogen	775·0
Aqueous vapour	14·2
Carbonic acid	0·8
	1000·

Whether we climb lofty mountains, or take the air at the sea-level, this composition is found to be everywhere the same. But, in spite of this fact, it is very capable of change: it parts readily with its oxygen, and is, therefore, easily decomposed; iron, for instance, facilitates its decomposition by its affinity for the oxygen of the air, which it

subtracts, and, mixing with it at its surface, produces what we call rust, or oxide of iron. This property of parting with oxygen, is a most important feature in reference to vegetable and animal life: all organic bodies require oxygen to live, but they obtain it with a certain amount of mixture, and cannot breathe the pure gas; they do not, indeed, require the nitrogen, but it forms a medium for the conveyance of the other gas, and, by a delicate arrangement, the proportion is such as is best adapted to their wants. It is not known how far either animals or vegetables are capable of adjusting themselves to differently proportioned atmospheres; but, on the other hand, there is no evidence that such different proportions ever had existence.

Perfectly dry, air would, however, be eminently unfitted for the purposes of life. We find, accordingly, that air has not only the power of absorbing a certain amount of moisture, but that it absorbs it greedily, becoming charged with water, not merely in the state appreciable by our senses, and forming mist, steam, or cloud, but mingling with it, under ordinary circumstances, and in a manner altogether invisible. In fact, air receives water by a process and in a manner resembling that by which fluids dissolve certain solid bodies.

The capacity of air for water depends very considerably on its temperature, and it is mainly owing to the variable conditions induced by changing temperature that most of the phenomena connected with the atmosphere are really produced.

In considering the relations of the air, its mode of action must be carefully regarded. Unlike a solid body, which is contained within a limited surface—which has a definite shape, and an ascertainable volume and weight; unlike water, also, and other fluids, which can be retained in vessels while we manipulate concerning them and ascertain their properties—air is invisible and intangible, and so elastic as to accommodate itself at once to any space within which it may be confined, and filling all space which is not otherwise occupied. Still we must always bear in mind, that the aërial condition is strictly a form of matter. Air is heavy; it presses and weighs down exactly in proportion to the quantity of matter it consists of, and is thus modified in respect of weight, both by the quantity of water it includes, and the temperature it is affected by. The atmosphere is limited in extent, notwithstanding its expansibility; it probably reaches to a height of sixty or eighty miles beyond the mean level of the sea, but there terminates absolutely, although it gradually becomes of less density in its higher districts. We can only judge of the condition of the limits of the atmosphere by optical and electrical phenomena.

In mentioning the composition of the atmosphere, it has been referred to as the important agent for supplying oxygen to the plants and animals living upon the earth, and this is, no doubt, one of its most important uses in connection with organic existence. Without it, life, in the sense understood by us, could not possibly have place upon the earth. But it is not only by supplying in its proper proportion a material essential for carrying on life, that the air is directly related to the living beings on our globe.

It is also adapted to the exercise of our senses; and first in this respect is its relation to light. The sun gives us the great proportion of light which we enjoy, and the reflected light of the moon is also very important; but how very little of either do we receive in direct rays. The light of the sun would be of small advantage to us but for the existence of an atmosphere; without it we must, in all those places where the rays were intercepted or were not directed, remain in utter darkness, and when the sun had set no twilight would moderate the transition to night. All intermediate conditions between positive brilliancy and total darkness would be wanting, were it not that the atmosphere

we enjoy has the property of reflecting rays of light in any direction, just as a looking-glass. Each particle thus lends to its neighbour, and we have a graduation and equalization of light. So again with reference to sound: this, in the absence of an atmosphere, would not travel, for what is it but the effect on our ear of certain vibrations of the air, without which it could not reach from one point to another? Without the adaptation of the air to the transmission of such undulations, the earth would be a soundless space, destitute not only of all the enjoyments which we derive from its various modulations, but also unfit for the use of our present methods of communicating with each other. The sense of smell is another faculty, the use of which depends on the existence of air. It is true that odours are given off from bodies, but these are conveyed to our organs of smell by the air. We have thus three senses—sight, hearing, and smell—depending entirely for their exercise on the existence of the gaseous envelope of the earth.

There are three ways in which we must consider the atmosphere to gain a view of the important purposes and ends it fulfils in the system of nature: first, as in motion; second, in its influence on moisture; and third, on climate. But the chief consideration of the two latter must be reserved till we have explained the chief phenomena of water and land.

The ordinary movements of the air depend chiefly on changes of temperature, and are consequent on the great and ready mobility of the particles of air, when separated by heat, or brought together by cold. Wind is only air in a state of motion; but how is this motion originated? We shall see this by taking the case of the sea-coast within the tropics. The sun shines with great heat equally on the land and the water, but it affects them differently. Shining on the earth, it causes it to receive a large accession of temperature, but, as the earth is a bad conductor of heat, its surface remains comparatively hot; shining on the water, a smaller quantity is absorbed; but, on the other hand, all thus obtained is rapidly communicated, by reason of the conducting power of aqueous particles, throughout the whole mass; and thus any great accumulation of heat in one part of the sea is precluded.

By virtue of these properties of fluid and solid matter, the air is, at different parts of the twenty-four hours, subjected to a periodic change, in weight as well as temperature, like a continuous ebb and flow. Within the tropics, the barometer is twice at its highest elevation—viz., about nine A.M. and ten P.M., and twice at its greatest depression. This alternation is carried on with the utmost regularity, and without reference to other changes, so that it might sometimes even afford the means of ascertaining, with tolerable accuracy, the hour of the day. Within the tropics climate is modified by the gales, which in the day set in from the sea, and in the night from the shore. These constitute the land and sea breezes; they are the result of the alternate rarefaction and condensation of air by the heat of the sun in the day, and the cold arising from radiation at night. These, however, are causes acting only within limited districts, and we must look for other causes to account for those larger and more general displacements which are common to a far more extensive range than that we have just noticed. We must have regard to the configuration of the earth, and the manner in which it receives heat. As a globe revolving on its own axis, and receiving heat from the sun, to which its surface is not equally and alike exposed, we know that it will be heated in proportion not only to the length of time, but also to the angle at which the rays of the sun strike it. On this account the tropics, on which these rays fall most vertically, are the hottest parts. In consequence of the expansion of the air when heated, which takes place in

accordance with the known laws of the action of heat upon any gas, the density of the air is then lessened, and it ascends to a higher region. To compensate for this loss, and to restore the equilibrium, a body of cold air rushes from the north and south poles towards the equator. But besides these two currents, whose region is the lower part of the atmosphere, there must be two others which convey the air which has been rarefied over the equator back again to the poles. This air, however, travels along at a great altitude by virtue of its small density until it reaches its destination at the poles, and becomes condensed. But these tendencies of the air to circulate to and from the poles and the equator are greatly modified by the motion of the earth from west to east. Revolving in this direction, the earth drags with it its gaseous covering, which, however, being of much less density than the earth, is less affected by the momentum with which that body revolves, and is therefore partly left behind. In consequence of the earth being a sphere, its motion on its axis near the poles is nothing compared with that at the equator. Thus, on the whole, a westerly direction is given to the polar currents.

A part of the air being left behind by the earth in its motion, sweeps the surface in a direction opposite to that of the earth. This forms the trade-winds, which are met with 28° north and south of the equator. The joint result of this direction of the motion of the air, one current being from the east, and one from each pole to the equator, is the formation of two winds, one, formed by the currents from the north pole and from the east, blowing to the south-west, and the other, formed by the southern and eastern currents, setting towards the north-west. These, however, are periodical winds, depending on the relations of the earth to the sun at different periods of the year, and having reference also to the form of land. Of this character are the monsoons, which blow within the tropics from the south-west from April to October, and from the south-east from October to April.

It is not known with certainty where particular winds originate. Most of the phenomena which we have been able to observe, however, show its commencement on the land, and indicate dependence on its configuration and physical conditions, such as the accumulation of a great mass of land in the northern hemisphere.

After the motion of the air, its condition, as charged with moisture, may be noticed. The facility with which hot air takes up water is well known. In its evaporated state water is easily conveyed over the land, and the quantity is sometimes very great. Sometimes, by the passage of a body of dry air, lofty mountains, as the Andes, have been denuded of their covering of snow. The changes in the state of the atmosphere are due partly to changes of temperature, and partly to changes of electrical condition. The causes are difficult to make out, but they are unquestionably connected with these agents. It is easy to understand how air, passing over water, is capable of changing its state to that of vapour, and how afterwards it is condensed; but it is necessary to consider the subject with reference to different parts of the earth, because there are some facts affecting the falling of rain, which are not alike in all countries, and which present difficulties. When the air is charged with aqueous vapour, so that it cannot hold any more, any reduction of its temperature will manifestly bring on a precipitation of moisture.

The air during the day is heated by the sun, and in that state, passing over the water, absorbs a portion. After sunset the earth cools the air at its surface, which is therefore less capable of retaining moisture; it becomes denser, and deposits its moisture in the shape of small drops; and we have thus the ordinary phenomena of dew in our

own country, and in the temperate zone. When, however, instead of this change taking place after sunset, it occurs during the day from a variation of the wind, or some other cause which we shall have hereafter to explain, then, instead of this dew, we have small vesicles, or rather globules, of water suspended in the air, which, if near the earth, form mist, and, if above the earth, become clouds. If this happen over the surface of a large body of water, as the sea, it may be blown by the wind to a considerable distance till it reaches the land, where it is differently affected, according as the land is of a high or low temperature. If, in its progress, it encounters two currents of different electric condition, we shall have, perhaps, a hail or thunder storm. Snow is produced when the temperature of the air is at, or a little below, the freezing point of water, and is composed of drops very perfectly crystallized. When the temperature is much lower, the water forms into hard grains.

The quantity of rain falling in different places, at different parts of the year, varies remarkably, and affords matter for the most interesting speculation. Some districts are totally destitute of rain, though no doubt air, loaded with aqueous vapour, passes over them as well as over other places. In South America an earthquake is a much commoner phenomenon than a shower of rain. On the whole, a much greater quantity of rain falls near the sea than inland, while vast tracts of land in the interior of continents often receive a very small supply. A much greater quantity of rain is observed to fall in Portugal than in France, and much more in the southern parts of England than in the northern. On the east coast of Spain there are places where rain does not fall for many years together.

Such, then, are some of the appearances and results consequent upon the thin, transparent, and often-forgotten veil of air which surrounds our globe. Without it our existence could not continue; the whole surface of the earth would at once relapse into the darkness and stillness of the grave. Without it we could not see; we could not hear; we could not breathe. Without it the sun might shine; but his beams, communicating light and heat, would be useless to us, and to all nature around us. There would be no distribution of heat or moisture; no beautiful sky to contemplate; no refreshing rain; no purifying wind. The absence of this one—perhaps it may seem the least important of the powers around us—would involve immediate destruction to every living thing. On the other hand, its presence insures those changes, and produces those modifications of the great powers of nature that minister so much to our necessities, our comforts, and our enjoyments. It is surely worth while to know something of a portion of the globe which exhibits so much that is interesting, as well as prevents so much that would be destructive.

It is also well to notice here, that as by the atmosphere we are enabled to appreciate and use light, so by light, by the propagation of luminous waves through that infinitely subtle ether which pervades all space, do we enter into relation with all forms of matter, whether existing in spheres which roll onwards in their course, or forming that portion—if portion there be—which exists still in a dispersed form. Light, propagated by undulations, and sound—the propagation of force through matter,—these are strictly analogous phenomena, and these connect celestial with terrestrial mechanics. All matter in the universe is governed by the same law of gravitation, and all matter is connected by the atmospheric or etherial envelope, which, in one way or other, is existent everywhere.

Water.—There are few objects in nature more striking or more affecting to the imagination than the contemplation of a great body of water accumulated within a

single area. This appears to be the case whether, standing on a lofty prominence, at the extremity of some tract of land, we watch the long swell of a great ocean rolling steadily but unceasingly, and dashing at regular intervals against the shore beneath us, or whether, borne across the wild waste of waters, we see reflected on the surface the perfect vault of heaven, or listen to the fury of the storm; whether we admire the tints of evening, or watch at early dawn the emersion of the sun from the bosom of the ocean; whether we trace the constant flow of a mighty river, as it moves ever onwards in its course, or whether, planting ourselves at some favourable spot, we listen to the noise, and watch till we are giddy the boiling torrent of the waterfall. In whatever way we allow our imagination to dwell on this theme, it still presents the same idea of vastness, indefinite power, and untiring motion. The sea and its tributaries, under all circumstances and in all respects, thus deserves special notice in treating of Physical Geography; and in endeavouring to picture some of the many instructive phenomena presented by the various modes of action of the aqueous veil that partly covers our globe, I shall be appealing to feelings readily excited, and only requiring to be recalled that they may be considered in their mutual bearing.

When we class the phenomena, we shall soon perceive their meaning and importance. Thus, the great facts of the distribution of water on the globe require to be considered by themselves as of great and immediate bearing on the history of the globe. We must, however, also bring under consideration the motion of water—its waves, its tides, and its currents—its mode of circulation, and the means of obtaining that constant supply necessary for fertilizing the earth, and rendering it fit for animal and vegetable inhabitants. And then, lastly, there is the effect of moving water upon land: so that many very striking and interesting phenomena are introduced, much observation is needed, and many conclusions are arrived at by the consideration of the part of the subject now before us. I shall only be able here to point out the principal direction which observation has taken, and inform the reader of a few of the great results. It is a subject full of novelty, full of difficulty, and full of interest; and connected as it is directly with the subject of Meteorology, it is already assuming, under the name of Hydrography, or Hydrology, the character of a definite science.

The first part of the subject involves, as I have said, the distribution of water on the globe. The details of this,—an account of the names and dimensions of those portions of the great ocean, or of those large bodies of fresh water forming lakes, which, from the position and form of land, have been designated by different names,—all this belongs rather to Descriptive than Physical Geography.

The distinctions we have here to draw are of another kind. We wish, for example, to draw attention to the fact that different seas have very different physical conditions; that there are some large tracts occupied by salt, and others, smaller but also important, by fresh water; that there is, in some parts, open ocean, and in others a sea dotted over with numerous islands; that there are large tracts of deep sea, and others of shoal water; and that, while the great body of the ocean is fluid, there are small portions near the poles constantly occupied with water in a solid form.

The water on the surface of the earth exists either as open ocean, connected throughout, and having everywhere the same, or very nearly the same, mean level, and the water collected from the clouds, and rushing down with various degrees of rapidity, to lose itself once more in the ocean from which it was at first derived. The ocean, however, is *one* essentially, and is only connected with the other waters by a constant circulation arising from ever-varying conditions of tempera-

ture, within certain limits, which are characteristic of the present position of our earth in space.

The general proportions of water and land are clearly as 10 to 3, but the distribution is altogether irregular, the land being almost confined to the northern hemisphere, which we may, therefore, call the area of the land, while, in like manner, the southern may be looked on as a vast area of water. Besides the usual constituents of water, that of the ocean is greatly impregnated with extraneous matter, the principal of which is common salt, in the proportion of three per cent., or one-thirty-eighth of its weight. The density varies somewhat, increasing towards the tropics, but depending locally on the amount of fresh water thrown into the sea by rivers. Doubtless this saltness is important, by reason of its adaptation to some forms of animal life, but there is no ground for the supposition which has been put forward, that in its absence the water would become impure or putrid.

The distinctions of the seas, some being open or inland, others forming bays or gulfs, according to the shape of the coasts by which they are bounded, need only be mentioned. The principal accumulations of water are called the Pacific and Atlantic Oceans, the former extending from the western coast of America to the eastern side of Asia on the north, and reaching the antarctic circle in the south. The Indian Ocean, though a portion of the Pacific, is sometimes designated by its own name. The Atlantic, differing from the other in some striking respects, extends from the west of Europe and Africa to the east of America, and presents some of the peculiarities of a river valley, its two opposite sides bearing marked relations to each other, both of figure and position. Thus, looking at the map (see Fig. 2), we see the projections of one coast answer to corresponding indentations on the other. In its narrowest part, between Europe and Greenland, the Atlantic canal is about one thousand miles wide, whence it opens to the south-west, according to the shape of the two continents, and attains, in the northern tropics, the breadth of more than four thousand miles; below this point it inflects to the north-west and south-east, in which we again discern the correspondence of the two coasts. This form of the coast lines, combined with the prevalent currents, contribute to produce some striking results, which will appear presently. Notwithstanding the great efforts which have been made, and the hardships endured in exploring the polar seas, little is as yet known respecting them. Since the voyage of Behring, there has been no doubt that Europe and America are disconnected by water on the Atlantic side: and the important problem that has recently been solved, in proving the possibility of a north-western passage, determines the question long discussed as to whether or not the land of the two continents were connected towards the north pole. In addition to the two great oceans, we meet with salt seas occupying a position in the land similar to that of a peninsula in the water, being almost surrounded by it, whence they are called inland seas; such are the Caribbean and Caspian Seas.

The general depth of the ocean is at present only a matter of speculation, as in many parts no line as yet has reached the bottom. There does not, however, seem any reason to suppose that its mean depth bears any corresponding relation to the elevation of mountains. It is generally in the open sea, at a distance from land, that the depth is greatest; but this is not universally the case, for in the Pacific the bed of the sea has an abruptness which has nothing corresponding to it among mountains. The range of temperature of the water is not so great as that of the surface of the land, which will be easily understood by a reference to its tendency to equality. With respect to its temperature at different depths, there is not that alteration which a consideration of the

tendency of heated particles to rise to the surface might have led us to expect. In some instances, however, a special agency is at work, whose operations we are able to follow. The most prominent of these consist of various currents beneath the surface, which convey the water of a colder region to a warmer. At a distance from land the mean temperature of the water at the surface is higher than the air of the locality, but this is subject to the variations of the air in the night and the day. Water is colder in shallow places, as on a bank, than where it exists at a greater depth.

The consideration of the tides is a subject of great interest, both as affording material for scientific research, and as bearing on the important art of navigation. Their connexion with the changes of the moon was noticed ages before her influence received any scientific explanation. That general influence which the moon exerts on our planet is modified, in the case of the water, by the capacity of its particles of motion amongst themselves. Our satellite moves out of its place a quantity of water in the shape of a wave on that side towards her, and this wave follows her apparent course. Thus the water of an open ocean would attain its greatest height, each day, at any given place, when that spot came beneath the moon's influence. At the same intant, however, the exactly opposite point of the earth would appear to be in the same condition, owing to the removal of the earth by the moon's attraction. There are thus two tides in each twenty-four hours. The sun, though so much more distant, also produces some effect, and thus when the moon is full, attraction being exerted by the sun at the same time, the tides are at the highest.

But, although these are the general effects, considerable modification takes place, according to local circumstances, such as strong gales, the form of land, the shape and size of the channels of rivers, &c. Thus, where the banks converge in the shape of a funnel, the tidal water is, as it were, gathered up and rises in height; but, if it expands from the mouth inwards, the tide dies away, and is lost; in the former way it attains, in the Bristol Channel, an elevation of from seventy to one hundred feet. The time of high water is irregular in narrow seas, owing to obstructions of various kinds; from a cause of this nature the tide of the German Ocean is twelve hours reaching London Bridge.

Connected with these phenomena are waves, which are of several kinds—the tidal wave, or wave of translation, which conveys its water from one part to another, and the oscillating wave, by whose agency the water undergoes no change of locality, but merely of form. These are the only two that are important in questions of Physical Geography.

The magnitude of waves is a matter which there is some difficulty in determining. The ordinary waves of the Atlantic have, however, been observed to attain an elevation of about twenty feet, with a length of one-hundred-and-sixty feet, and a velocity of twenty-five to thirty miles per hour. Dr. Scoresby gives about the same as the mean elevation with rather a hard gale a-head; but on one occasion, with a hard gale and heavy squalls, some few waves attain a height of forty-three feet, with a length of nearly six hundred feet, and a velocity exceeding thirty miles an hour.

Marine currents are of various kinds—one produced by the steady action of uniform winds such as the trade winds and monsoons, and not reaching below the surface of the water; another produced partly by the culmination of the water to the equator, owing to the form of the earth and the position of the land, and partly by the apparent tendency of the water to rise in a direction contrary to the motion of the earth on its axis. Owing to the mobility of the particles of water, these do not so readily

partake of the motion of the earth on its axis, and thus is produced an apparent motion from east to west; this is called the equatorial current. Another current, analogous to what we find in the atmosphere, sets in from the poles, and is occasioned by the rushing of the cold water to the equator. The waters of the Pacific Ocean, proceeding from

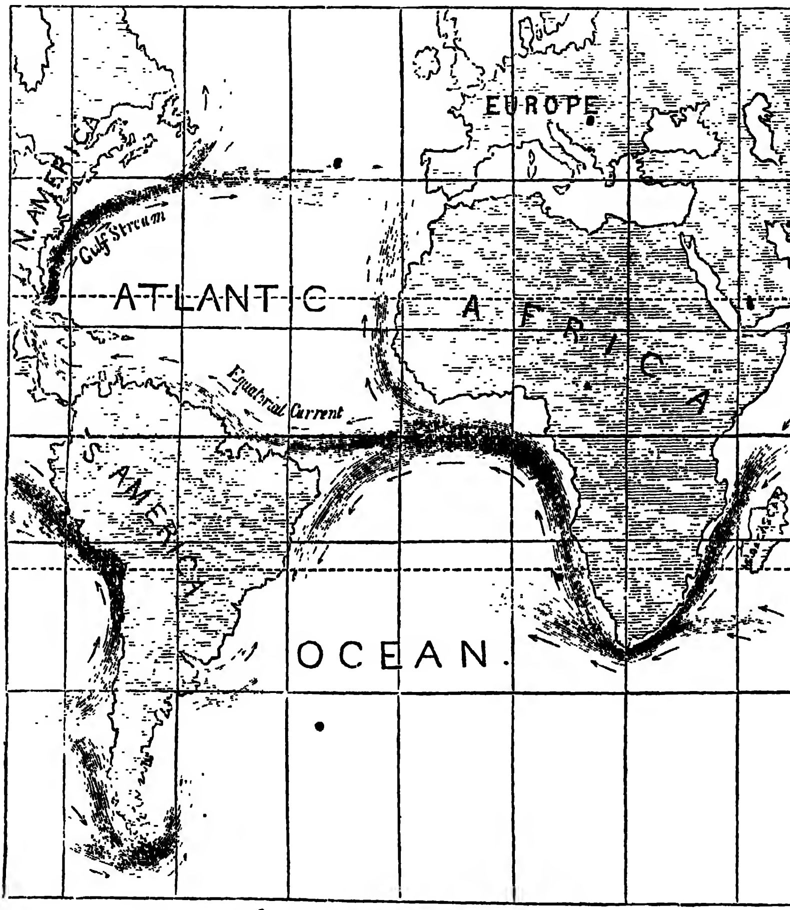


FIG. 2.—MAP OF CURRENTS IN THE ATLANTIC.

the antarctic circle, and crossing the equator, strike against the coast of Africa, producing a current through the straits of Madagascar (see Fig. 2). This coming down the south coast of Africa, meets another current, and both come round the Cape of Good Hope, where they divide, one part going towards the coast of America, and the other portion joining that current which is forced along the African coast, and rushing towards the equator. The former and principal part reaches the coast of South America in about the latitude of Guinea, and is broken into two portions—one going to the coast of Brazil, and the other to the Gulf of Mexico. This latter makes a complete circle in

the vast inland sea between the two Americas, and comes out near the coast of Florida, taking a northerly direction, and re-crosses the Atlantic to the shores of Europe. So certain is the course of this circuitous current, that bottles cast into the sea at the part where this stream has its rise have been often found, after a certain time, on the coast of Spain. The mean speed with which this body of water advances is ten miles per diem, but in some parts of its progress it flows much faster than at others; that which comes from Mexico to Florida, called the Gulf Stream, travels at the average rate of thirty-eight miles a day, and, therefore, there must be in some parts a very slow motion. Such a current as this has, however, very important effects. The body of water running along the coast of Africa across the equator, becomes much warmer than when at the Cape of Good Hope, and it is not chilled by passing through the Gulf of Mexico. This vast body of water, three hundred miles broad, of considerable depth, and issuing very warm, tends to elevate the temperature and modify the climate of the coast of Europe. Were the shape of America different from its present figure, however, and the current not forced on one side, warm air would not then be conveyed, and the temperature of Europe would be considerably changed. Another important oceanic stream is an Arctic current coming down from the poles, and bringing with it not warm air, as in the other instance, but a body of ice. This current, impinging on the banks of Newfoundland, produces constant fogs, which, for weeks together, never move from the coast.

Clouds and Rain.—By the constant evaporation going on from the surface of the earth, as well as from the sea, moisture is continually being drawn up into the clouds, and conveyed to different parts of the earth; after which, by various causes, it is condensed, and precipitated on the land. This occurs particularly in mountainous districts, from which most large rivers take their rise—as the Rhine and the Rhone. Some, however, instead of rising among mountains, originate in a spring; of this number is the Danube. Their course is dependent on the physical structure of the country and its mountain chains. Where a river valley is large, the declivity is generally less considerable than where it is more contracted.

The formation of clouds and the precipitation of rain are intimately connected with the origin of rivers and springs. The moisture which is extracted from the earth is capable of being absorbed by air, according to its temperature, and in this state of vapour is conveyed to considerable distances. When, by the action of a cold current, the presence of a lofty mountain-chain, or any similar cause, this body of air is chilled, it is no longer capable of holding its moisture in suspension, and deposits it, according to the temperature at which its condensation takes place, in the form of rain, hail, or snow. The quantity of water collected may either form a river, or, penetrating some permeable strata, run under ground, till, finding some external outlet, it issues as a spring. These springs, resting on impermeable beds, often run to a considerable length before they find an opening. The general temperature of springs is the mean of the climate in which they exist, but where they rise from a great depth they are usually warmer. Their water is always charged with some air, and many of them contain mineral substances, as carbonic acid, sulphureted hydrogen, or nitrogen gases, soda, ammonia, magnesia, &c. There are also thermal springs, having a temperature very much elevated above that of the surface.

The quantity of water received from the atmosphere upon the land, in various parts of the earth, is very large, being estimated at not less than thirteen hundred millions of gallons per second throughout the whole year; at least one-half of this

quantity is believed to run off the surface into the sea directly by the various rivers distributed in all lands. Of the other half, a large part is re-evaporated, and the remaining portion passing within the earth, supplies natural springs, and keeps the absorbent rocks fully charged with moisture.

Rivers and River Systems.—In another paragraph the subject of mountain-chains, table-lands, plains, and valleys, will come into consideration in detail. At present it is only necessary to refer to the commonest illustrations of these varieties of form, to show that the whole of the land must necessarily be divided into certain portions, within which the drainage will be constantly tending towards some one or more outlets. The various ridges that include such areas are called *water-sheds*. The springs, brooks, and rivulets which combine to form a river, and are thus conveyed either to the sea or some depression in the interior of a continent, form what is called a *river system* draining a *river basin;* and within each principal basin are often contained numerous and widely distant districts, and many considerable streams.

The largest by far of such basins are on the continent of America, where we find that of the Amazon, including within a single line of water-shed upwards of a million and a half of square miles of land—an area three times as great as that supplying all the European rivers that empty themselves into the Atlantic. This gigantic stream, the largest on the globe, runs more than three thousand miles (including windings) before reaching the sea. It is navigable almost two thousand miles from its source; is in some places six hundred feet deep, and is nearly a hundred miles wide at its mouth. More than twenty superb rivers contribute their waters to swell its volume; and the current of fresh water rushing from it floats over the denser brine of the ocean, and is easily recognised three hundred miles from the shores of America.

Nor is this noble stream without rivals, although none equals it in extent. The Mississippi, together with its main tributaries, the Missouri and Ohio, also drains a million of square miles of land. The Missouri only empties itself into and forms part of the Mississippi, after having run a course of three thousand miles, at a rate varying from four to five and a half miles per hour. While the Amazon, in its progress through tropical forests and untrodden wilds, must be regarded as the most gigantic of streams, the noble and majestic Mississippi still retains and deserves its title of the "Father of Waters," owing to the great number and importance of its tributaries, whose waters it carries down from the shores of the great lakes to the Gulf of Mexico.

The great rivers and river systems are to be regarded in reference to the oceans with which they are connected. Thus the Amazon, the Plata, and Orinoco, in South America; the St. Lawrence, with its vast lakes in the North; the Rhine and Elbe; the Neva and Vistula; the Garonne, the Loire, and Seine; the Tagus and the Douro; the Guadiana and Guadalquiver; and last in magnitude, but first in importance, our own Thames, are connected with many other European and many African streams, into the Atlantic group. The Nile, the Po, the Rhone, and the Ebro, form a Mediterranean group; the Danube, the Dnieper, the Don, and the Dniester, a Euxine group; and the Mississippi, the Rio del Norte, and the Magdalena, conveying their vast torrents into the Gulf of Mexico and Caribbean Sea, form yet another.

Besides those belonging to the Atlantic group and its adjacent seas, there are other river basins, less considerable in number, and less extensive, but still including some of gigantic magnitude, received into the Pacific and Indian Oceans, and others into the Arctic Sea. The former include the great Chinese rivers, draining nearly two millions of territory, and the rivers of India scarcely less extensive. The Amour and the Ganges, the

Irrawaddy and the Indus, are equally interesting for the extent and the mode of their development, and scarcely less so from historical associations, and the rich products obtained from their banks.

The Arctic group is much less known; but one river alone, the Obi, runs a course of more than two thousand miles, draining nearly a million of square miles; and two others are only less considerable in the area they drain, but surpass in magnitude most of the streams whose names are far more familiar.

Lakes and Inland Seas form, as it were, a series of connecting links between the small expansions of a river and the great ocean; and the Atlantic receives and connects not only the waters of the chief rivers, but those of the largest and most important of these bodies of water.

The chain of the great lakes of North America, notwithstanding their vast proportion and great depth, are but occasional hollows in table-lands, imperfectly drained by the rivers that traverse them. The lakes of Europe, small, indeed, compared with these, partake of the same character; and the inland seas, of which the Gulf of Mexico and Carribean Sea, on the one side, correspond with the Mediterannean and Euxine, of the other, are open to the ocean, and their waters are freely mixed by currents, though imperfectly in the latter case, owing to the narrowness of the neck. All these bodies of water have their peculiar characteristics, and produce much effect on the adjacent land. They each possess a history, and each has seen many changes ere it attained its present form.

The characteristic features of river scenery vary in different countries, being greatly affected by the nature of the rocks traversed. High bluffs of soft sand and earth; vast open plains, with little elevation in any part; narrow rocky gorges; sudden changes of large tracts from a high to a low level—these all may be mentioned as among common, though not essential, features. We shall have to consider, in a future page, the effect of running water under these various conditions, and the meaning of these peculiarities, when translated into geological language.

Distribution and Form of Land.—The proportion of land rising above the mean level of the ocean, has been already stated to include only about three-tenths of the surface. This portion, however, though comparatively small, presents so much variety of form and condition; so many different rocks, vegetables, and animals; such varieties of soil, capability, and climate; and is so much more important to us as men than the rest, that we not only are able to study it more closely, but find it necessary to do so for the purposes of existence, as well as the advantage of science.

In Political and Descriptive Geography the land is divided into various ideal and conventional portions, with which, as geologists or naturalists, we have nothing to do. We have here to consider our globe in a very different point of view, noticing only those broad and well-marked natural features of the earth which give it its characteristic physiognomy, and which distinguish its surface from that of other planets, as the face and figure of one human being are distinguished from that of another.

What are these features? They are the mountain-chains, or bones of the earth—the undulating hills of heaped material, which may be called its flesh—the covering of vegetable soil, which may be regarded as its skin—while over large portions there is that even and formless accumulation of water which conceals so large a part of the bony framework and softer contours, but which no more influences the true ultimate form of solid matter, at any given moment, than the dress affects the bony framework of the man.

In commencing this part of our subject, we must assume that the earth has such a skeleton; that the aqueous covering only partly conceals this skeleton; and that the framework is, to some extent, traceable, even where the ocean covers it.

A knowledge of the actual skeleton of the earth is, then, a study far more difficult than that of the mere surface exposed above the water. It involves not merely a careful consideration and comparison of the exposed surface, but a carrying out of some principle of form into the unseen depths of the sea, and the tracing from some obscure history of the past, also to be learned, the modifications which helped to produce what we perceive, and which must, in certain cases, have done much more on a yet larger scale.

The various circumstances under which the land presents itself to our notice, are, indeed, too familiar to require any lengthened description; but when we sit down to an examination of them as exhibited on a globe, we find some facts differing from what we might be inclined to expect. Thus it might be thought, judging from the earth's form, that the solid portions should lie pretty equally about the equator, instead of which we find great masses of land in lines parallel to the axis of the earth and accumulated in the northern hemisphere: these comprise, on the one side, Europe, Asia, and Africa; and, on the other, the two continents of America. On looking at these masses of land, they are all seen to partake of a triangular form. In the eastern hemisphere, the chief extension is east and west, but all the lands terminate in points directed southwards. The different continents, considered with reference to the countries which they comprehend, show the same principle, yet further carried out. We must, however, regard this simply as an observed fact, and not one on which any conclusions are directly based. We do not know why the form of India or Arabia should be the same as that of Asia or Africa; but, although we can offer no explanation of this peculiarity, it is one well worth noticing, as it may be found to have important bearings, and, as a fact, may become the foundation of reasoning. Besides the vast preponderance of land in the northern hemisphere, we may observe that the eastern division of our globe contains a far greater proportion of land than the western; and this fact, also, is worthy of remark, in its bearing on various peculiarities of climate.

The whole of the connected land above the water may, with advantage, be considered separately, although often having intimate relation to adjacent portions separated only by a narrow breadth of water. The form of land must also be studied, together with the lakes and streams by which it is partially covered. It is found convenient to group the whole into three principal and many subordinate tracts, which are removed from each other by a greater or less extent and depth of water. Of these the former and larger tracts are the continents, properly so called, and the others islands; although, as has been said above, the latter, in many cases, are so closely adjacent, that they may be conveniently regarded as detached portions of the larger masses. The three continents are of very different magnitude, form, extension, and position. One of them extends chiefly in a north-east direction, and includes the whole of Europe, Asia, Africa, and the islands adjacent; another includes the two Americas, almost detached, but still connected by a narrow but lofty isthmus, and ranges nearly north and south; while the third is at present exhibited only by the rounded mass of Australia, which can hardly be said to possess extension in any one direction rather than another, but which seems, like America, to possess a north and south bearing in the portions best known and most investigated. With Australia, however, must be grouped several islands, of which Van Diemen's Land and New Zealand are the chief; whilst America has few

examples of detached land along a great part of its coast, although the West Indies, and the islands round its northernmost portion, are important exceptions to this general rule. We are naturally accustomed to regard chiefly that portion of the first-named group of land with which we are directly associated; the whole of which, from its vast extent, is sometimes called the great continent, and which, from its having been apparently the first peopled by the human race, and presenting to us the chief records of mankind, is also known as the Old World. This latter term is, however, strictly applicable only to the land as known to the ancients, a limited proportion of the district, including a part of each of its three principal subdivisions.

Continents.—The great continent includes Europe, Asia, and Africa—the latter being almost detached from Asia at the isthmus of Suez, and almost connected with Europe at the straits of Gibraltar. Europe and Asia offer no well-marked natural line of separation, and the accepted and political division consists partly of a low mountain chain, and partly of a river. Thus the land of Europe does not readily resolve itself into its true and great natural features, and can only be properly understood, in so far as its physical geography is concerned, by a reference to the adjacent land, even to the extent of almost the whole of Asia, and a large part of Africa.

The continent of Europe, with which most of the readers of these pages are doubtless best acquainted, is not without the means of suggesting some important generalizations of science, while in matters of greater detail, and perhaps more universal interest, it presents abundant matter for illustration. It contains within it about four millions of square miles (about one-eighth of the land of the greater continent), and possesses ranges of lofty mountains, piercing the clouds, and several of them covered with eternal snow. Rivers of frozen snow proceed from some of these, and make their way into the sheltered valleys below, loaded with fragments of rock torn from numerous jagged pinnacles that appear, indeed, to be permanent, but are, in fact, only constantly renewed in similar form. It contains, also, a multitude of rounded and undulated hills, of lesser elevation, some of them clothed by vast forests of pine, others covered by chestnut and oak, while others again are smiling with corn-fields, or laugh with the yet richer luxuriance of the vine. It exhibits noble rivers, traversing extensive plains—not, indeed, rivalling in magnitude those vast streams already referred to, which pour forth their torrents into the Bay of Bengal, the Persian Gulf, the Yellow Sea, the Caribbean Sea, the Polar Seas, and the western side of the Atlantic, but more than equalling them in their adaptability to the wants and comforts of civilized man, and brought within those limits which encourage industry, by calling forth the talents and energies of our race. It embraces, also, lakes and inland seas, presenting a rare variety of extent and usefulness. It has around it islands admirably placed for commerce, and admirably supplied with the means of availing themselves of this position. It is blessed with a climate, offering, it is true, much change, but nowhere ill-adapted to call forth the exertions of man, to tax his ingenuity, and to necessitate the cultivation of his highest intellectual powers. It is, for the most part, healthy and cultivable—rich, but needing, and amply repaying, labour; abounding with the most useful minerals, and now covered by the most useful animal and vegetable tribes—many of them, it is true, introduced by man, but all adapted to its condition, and most useful in their present state. Blessed in this way with so much that is excellent, seldom injured by the passage of periodical storms, rarely suffering from earthquakes, and gradually, it would seem, less and less frequently visited by pestilence and famine, as the advance of civilization points to the best means of avoiding them, we

may surely say that Europe has the elements of greatness and happiness; and we know that, up to this time, she has led the way in all essential points of civilization.

If Europe offers these matters of almost personal interest, the remaining part of the great continent is also crowded with phenomena which in magnitude surpass the others. The lofty mountain chains of the Himalaya, the vast and trackless deserts of Central Africa, the steppes of Tartary, the basins of the Ganges, and other rivers of the first class in Asia, and the volcanic islands of the Eastern Archipelago are each and all worthy of study, not only in themselves, but in their bearing on the general questions of Physical Geography that bear most directly on Geology.

The land thus grouped into one mass ranges from north-east to south-west, being terminated northwards about the seventieth parallel of latitude, and pointing, as has been already said, by a number of triangular projections, towards the south. It includes numerous lofty plateaux, and innumerable smaller plains and river valleys, the surface being much broken in almost every direction, and its coast line indented to so great an extent, that it would take a line of nearly seventy thousand miles to follow all the irregularities around its edge. Situated chiefly in the northern hemisphere, and most part of it, indeed, within the north temperate zone, there are many similarities over a wide range which would be much more marked, were it not for the spurs or transverse ridges extending from the great mountain chains, which separate districts otherwise under nearly the same conditions.

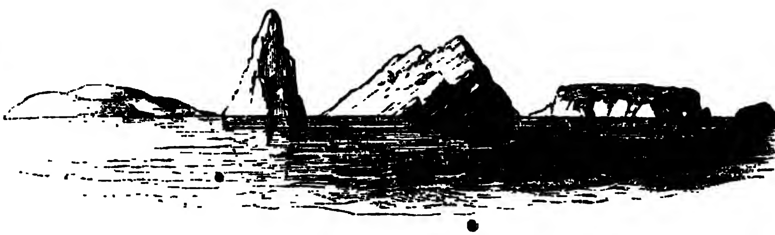
The continent of America contains about fourteen and a half millions of square miles, and is not only smaller but much simpler in its form than the land of the Old World. It has in all a coast line of upwards of forty thousand miles, but a great part of the shores are unbroken, and present but few bays or gulfs. Those that do exist, however, are large and highly important, especially the vast Gulfs of Mexico and the Caribbean Sea, and the important Gulf of St. Lawrence. South America corresponds well in form, and in some other peculiarities, to Africa, and the shores of the great Atlantic canal appear, as it were, to correspond—the projections of one fitting into the recesses of the other.

While the longer known and larger mass of land contains the loftiest summits of our globe in the Himalayan chain, the most savage and dreary wilds in the Sahara of Africa, and the grandest high plateaux in Tartary, Central Africa, and Spain, a high degree of interest also attaches to the mountains of America, with their conical volcanic summits so frequently piercing far above the general range of the Andes, and to the prairies of the north and the silvas and llanos of the southern part of the same land, which are almost equally extensive and more uniform than the plains of Asia, but are far less elevated above the sea.

Islands.—Leaving the larger portions of land, or continents, and passing to those which are called islands, we meet with them—first, as existing in immediate proximity with the large solid portions of the globe, and thence called continental islands. These generally have a peculiar form, or, rather, follow a peculiar law: they extend in the direction of the main land, and often partake of its form. An illustration of this law is presented in the island of Madagascar, which extends along part of the east coast of Africa. They frequently also exhibit the same physical structure as the continent towards which they lie. There is thus in Madagascar a mountain chain just parallel in its position, and analogous in character to another which runs down the continent of Africa. The islands in the Baltic Sea corroborate this general law.

But if, leaving such islands, we go to the open sea, we find the land arranged there

in a different manner, dotted about irregularly, and sometimes collected into groups. In the latter case the islands occasionally rise directly from the deep water, often at



FORMS OF ISLANDS.

great distances from other land, and exhibit outlines of a most remarkable character—in some places circular, at others oval, and forming disconnected chains.

The third class may be termed islands of elevation, bearing evidence of volcanic origin, either directly, by an actual cone and crater, or ashes abundantly distributed, or indirectly by the circular form of a tract of land, now perhaps consisting of little more than the secreted limestone of the coral animal, which we know must have been con-

THE NEEDLES.

structed under water, and which, to have attained its present mass, must have needed, first, a long period during which there was depression, and another period when the sea-bottom was undergoing elevation.

Action of Air and Water on exposed Coasts.—The form of land, at its termination towards the sea, frequently furnishes interesting and instructive facts, both in Geography and Geology. If we look at the coast-line of some gulfs, we find detached rocks jutting out towards the sea, and we cannot doubt that the whole is undergoing change by the action of the atmosphere and water, although the shape remains the same for a very long period. The rocks called "The Needles" once formed the western extremity of the Isle of Wight. The chief of these, and that which gave its name to the group, was a hundred and sixty feet high, and disappeared in 1764, being undermined by the sea. Other parts of the coast, similarly exposed, but formed of layers of various formations and different degrees of hardness, are more susceptible of modification by the operation of the same causes, and yield even more readily to their action. In this way the forms of coast-lines are gradually changing, and the boundary of land and sea relatively altered.

The action on land of the water falling from or contained in the atmosphere is very much regulated by the form and distribution of mountains. In America, where the principal rivers run southwards and eastwards, descending from the higher and more elevated part of the land and from the mountains, and rushing impetuously to the sea, they deposit large quantities of detritus, not only along the sea-coast, but also at a considerable distance beyond it, into the ocean. The changes thus brought about, although not of a nature to be readily detected in individual experience, must, from the unceasing action of their causes, be very extensive and important.

Mountain Chains.—Looking at the great mountain chains of the world, we cannot help observing the tendency of many of them to take the direction of the coast-line of the continent of which they form parts. In South America the Andes run parallel with the coast all the way. Turning to the eastern hemisphere, we find the same conditions in Africa, on the east coast. The mountains of Scandinavia also range parallel to the west coast of Europe; and, by continuing the line across the sea, it will connect itself with the mountains of Scotland and Wales. These facts, taken in connection with the tendency of the islands to follow the coast-line of neighbouring continents, are important. The very general observation of such facts has given rise to an opinion that all the mountain ranges lie in the same direction as the earth's axis, or at right angles to it—an opinion, however, which is not borne out by the actual state of the case, since we find the line of the Alps extending in a direction neither of the axis of the earth, nor yet decidedly east or west, though having a

DIFFERENT FORMS OF MOUNTAINS.

tendency to the latter direction, and connecting itself on the west with the Pyrenees, and eastwards with the Caucasus, from whence a line of high elevation extends to the mountains of India.

The opposite sides of mountains are often marked by great difference in their steepness; and, while on one side the elevation approaches the perpendicular, and presents an outline of great boldness, on the other it dies away down to the plains. Thus the Alps on the Italian side present sharp and sudden prominences; on the other side, they are comparatively sloping and gradual. The Andes also form a line running from north to south, and rise suddenly from the coast, but on the other side they terminate in extensive and elevated plains descending towards the sea in some cases by successive steps.

In estimating the comparative influence of mountains on the surface drainage of a country, we must not merely regard their heights, since many mountain chains of the greatest importance are by no means so lofty as others which are of less consequence. The truth of this remark is exemplified in the Ural mountains, the political boundary of Europe and Asia. This range is comparatively low, but nevertheless determines the distribution of large and extensive bodies of water, and exerts a very important influence on the climate of the surrounding districts on each side.

Besides these, we may regard, as connected with the subject of elevations of land, the conditions of the plateaux and table-lands, of which the vast prairies of America, and, in the Old World, the steppes of Siberia, are examples. In Siberia, this elevation above the sea-level ranges from five to twelve thousand feet, and produces a marked effect on the mean elevation of the whole continent. In America, on the other hand, the elevations are small, and the plains often sink almost to the sea.

Besides the mountain chains and elevated plateaux, another form of elevation is frequently met with in isolated mountains, belonging apparently to no chain, and rising abruptly from the land, or, as is sometimes seen, from the bed of the ocean, and exhibiting signs of volcanic origin. Such mountains are comparatively rare, and are usually associated with volcanic phenomena.

As the counterparts of mountains, between which they generally lie, valleys possess much geographical interest, and perform a very important part in the drainage of a country. They are, for the most part, low, nearly level, and gradually sloping towards the ocean.

It is not always, however, that river valleys are broad and open. They are sometimes shut in so closely, that the waters of the stream can scarcely force a passage, and when on a large scale, they thus afford some of the most magnificent and picturesque scenery on the surface of the earth. The beautiful gorge of the Rhine, between Bingen and Coblentz, the iron gates of the Danube, that of the Saxon Switzerland on the banks of the Elbe, and other familiar European scenery, afford admirable examples of this kind.

Some of the whirlpools and rapids impeding the navigation of rivers, are also due to a similar condition, and to an inadequate passage for the body of water rushing along a channel. It is, however, worthy of notice, that some of the largest rivers, although extremely rapid torrents, have but a very small fall indeed. Thus, in the descent of the Ohio and Mississippi from Cincinnati to the Gulf of Mexico, a distance of nearly one thousand seven hundred miles, the mean fall is less than three inches per mile.

It must not be forgotten that the external form of land, the direction of its vertical, as well as horizontal extension, and the position of the great expanse of ocean, all have a most important bearing on climate.

Climate.—Temperature, although often regarded as almost synonymous with climate, is in reality but a small element in the complicated phenomena referred to by that word. Temperature itself, too, requires to be considered with reference to its

extreme limits, as well as to the mean of summer and winter, and of the whole year. Moisture, and especially the aqueous condition of the atmosphere, is another important ingredient. The pressure of the air, and the changes that occur in this respect, whether diurnal, seasonal, or annual; the purity, transparence, and serenity of the air; the nature of the prevalent winds; and the electric tension of the atmosphere,—these are all points of vital importance, without a due consideration of which no proper conclusion as to climate can be arrived at.

Thus it often happens that places having the same latitude, the same relative position on continents, and even the same mean annual temperature, differ exceedingly in climate, and are characterized by vegetation of an altogether distinct character; while others, in which these points, important as they are, vary exceedingly, are yet nearly similar in all the essential matters which govern climatal resemblance.

An instance of this has often been quoted in the case of Dublin, as compared with the banks of the Danube below Vienna, in the same latitude (54° 56′), and having the same average temperature (49°·2 F.).

In Dublin, the mean summer heat is 60°·8, and the mean winter cold 39°·8; while in Hungary, in the corresponding position, the summer heats average 69° 8; and the temperature of the winter months averages 27°·7. The climate of Dublin is that of an island surrounded by a comparatively warm sea, so that there is no intense cold, and snow rarely lies on the ground, but on the other hand, there is little heat in summer. The myrtle will grow in the open air, and resist the winter, but the grape will not ripen. In Hungary, on the contrary, the myrtle would be destroyed by the winter frosts, but the summer sun not only ripens the grape, but enables the inhabitants to prepare some of the finest and richest wine known in the world.

Owing to the constitution of the atmosphere, the temperature not only diminishes in proceeding from the equator towards either pole, but also in ascending from any place near the sea into the higher regions, whether on a mountain side, a lofty plain, or merely by some temporary contrivance, such as a balloon. At a certain moderate elevation, even in the hottest climates, we reach the limit at which water is no longer a fluid, and this limit, called the snow line, varies from about eighteen thousand feet under the tropics, to where it reaches the level of the sea in the Arctic and Antarctic circles. It will easily be understood, that not only actual elevation, but the vicinity of mountain chains, the extent and form of the surrounding land, and the influence of oceanic currents, which may bring warmer or colder water into a given spot, these all influence climate, and greatly affect vegetation.

The conditions of climate, so far as regards the state of the atmosphere and the distribution of heat—two most distinct and influential matters—will now, perhaps, be understood and appreciated. Europe owes its mild and average temperature—far different, in this respect, to corresponding countries on the other side of the Atlantic, or on either side of the Pacific oceans—to its intersected form and deeply-indented coast; to its exposure to the prevailing west winds which have blown across the ocean; to the sea, free from ice, which separates it from the Polar regions; and, lastly, to the existence and position of Africa, with its wide extent of tropical land, while the equatorial region to the south of Asia is, for the most part, covered by ocean. The European climate would, therefore, become colder if Africa were to be overflowed by the ocean; or if land were to rise from beneath the waves and connect Africa and America; or if the Gulf stream were to cease to extend its warming influence to the northern sea; or, finally, if a tract of land were to be elevated between Scandinavia and Spitzbergen.

The climate of other parts of the great continent is equally affected by local causes. Thus, as we advance to the east, the westerly winds become cold and dry. In the vicinity of great mountain chains the same deterioration is felt, and other conditions might be imagined by which changes would be produced, greatly modifying, and, perhaps, entirely changing the conditions of existence favourable to the existing races.

Questions and considerations like these are not only of abstract interest to scientific men, but have much direct bearing in a practical sense, inasmuch as climate greatly influences the modes of communication, the extent of intercourse, and even the progress and civilization of mankind.

For whatever causes diversity of form or feature on the surface of our planet—the mountains—the great lakes—the grassy steppes—and even the deserts—and, still more, the great river valleys, and the streams themselves, surrounded by a coast-like margin of vegetation, must impress some peculiar mark or character on the social state of its inhabitants. Continuous ridges of lofty mountains, covered with snow, impede intercourse and traffic; the lofty plains, narrow enclosed valleys, and table-lands serve as the last retreat of retiring and nearly extinct races; while lowlands, interspersed with discontinuous chains, and with groups of hills of more moderate elevation—such as are presented by a great part of Europe, especially near its western coast-line—are favourable for the pursuits of commerce; and the improvement of the races of domesticated animals, as well as increased cultivation, give rise to numerous modifications of animal and vegetable life, and suggest mechanical contrivances, which tend, on the whole, to the intellectual progress of our race.

In the rapid glance that we have now taken of some of the most remarkable of those world-phenomena, connected with the form of land and the distribution of land and water, the reader may, perhaps, have been reminded of what has often already presented itself to his observation, rather than be struck with any new facts communicated. But some of these facts may have been presented in a way not altogether familiar, and thus, perhaps, there may have been imparted fresh interest to a subject always, in one shape or other, before us. The mutual influence and the mutual necessity which bind together into one group almost all the great facts of nature, is also eminently shown in reference to this subject; and it is not the least important or the least instructive lesson, afforded by the study of nature on a large scale, that we learn to appreciate this as one of the great and universal truths. When also we see, as in the case before us, that the constant circulation of aqueous fluid—only to be performed, so far as we can know, by the agency of the atmosphere—is only practically useful in consequence of the form, the features, and the distribution of land; when we find the temperature, such as it exists, and related as it is to the existing conditions of matter, also perfectly in harmony with every other arrangement; when, in a word, we perceive throughout such perfect adaptation in every respect—not acting by a system of interference, but by definite methods or laws, which are constant in their mode of action—it cannot fail to strike every one, that this method of producing all necessary modifications in infinite variety of detail, is the method which the Author of nature has seen fit to adopt, and in the working out of which we are not at liberty to assume any essential alteration of principle.

Heat of the Interior of the Earth.—Among the great classes or groups of phenomena presented in the study of nature, those which involve motion are, in all respects, predominant. We have seen, in considering the most ordinary facts, with regard to the air and water, that these are most important and very widely influential; that the currents of air circulating constantly produce the modifications of

temperature on which climate depends. It has also been shown that the tides and currents of the ocean, and the streams that feed it, are essential to the present condition of things; and we cease to wonder at the fact, that air and water are so seldom in repose.

Our very language, indeed, speaks in proverbs of the inconstancy of the winds, and the fluctuation of the tides and the fluid and aërial conditions of matter are commonly contrasted with the relative permanency of the solid earth on which we tread.

And yet it appears, after all, that this permanency is only apparent. The earth, or at least that superficial crust presented for our observation, has its own movements and disturbances, by causes acting from within. These causes tend to burst asunder and destroy portions of the solid crust, and are connected with the presence of intensely heated matter existing far below the surface.

In order to judge of the nature of the relative magnitude and importance, and the actual extent of these movements, let us first refer to the ordinary condition, with regard to temperature, of the great depths of the earth, and this will lead us to an inquiry as to how far the interior condition does or may act upon the exterior surface, and how, from the position of those points at which the surface is reached, we can judge of the true nature and value of the phenomena.

The causes tending to modify the condition of the earth's crust, various as are their modes of exhibition, refer themselves, sooner or later, either to the presence of an internal source of heat existing at some point far below the surface of the earth, or else to the mutual mechanical action of air and water at various temperatures. To gain a correct notion of the operation of the first of these causes, we must inquire what is the ordinary condition of the matter of the earth's crust, and how its internal condition affects the exterior? The first thing that strikes us in this inquiry is, that whilst, to a certain depth, the mean temperature of the earth is dependent on that of the atmosphere, and differs in various localities, below that depth it uniformly increases. When we dig below the depth over which the influence of atmospheric temperature is felt, the thermometer rises regularly in a definite proportion; and when we descend to very great depths, as in coal mines, the temperature becomes so warm as to remind one of a tropical climate. The deepest coal-mine in England had for a long time, and till cooled by a constant circulation of air, a fixed temperature varying from 80° to 84°, and the natural heat at this depth has no reference to the thermometrical condition of the surface.

Hot Springs.—Increase of temperature below a certain depth is also shown by other means. Pits and wells have been sunk, for various purposes, and at different times, to great depths, and observations have been made in them with the thermometer. The results have given constant testimony to the law of increase of temperature according to increase in depth. Besides this, we have evidence of the same fact in numerous natural warm springs and wells throwing out their waters at various points on the earth's surface at temperatures differing from one another, but much higher than that of the local atmosphere. These springs are met with in many parts of the world; those of Carlsbad, Wiesbaden, and Bath, are familiar to all, and certainly tend to show that a source of heat of some kind exists at some point in the interior of the earth. But there are other districts in which this doctrine receives a yet further confirmation. In some parts of South America there exist springs at the bases of mountains covered with perpetual snow, the waters of which issue at a temperature removed but a very few degrees from the boiling point of water. Perhaps the most remarkable phenomena of this kind are the hot springs of Iceland. There exist in that island certain small hills; in the

middle of some of these are funnel-shaped basins, in the bottom of which are holes leading to a considerable depth. These basins are at times left dry, but water rises periodically in the pipe-like passage at a temperature of 212°, and fills the basin to overflowing. Suddenly a stream of boiling water rushes up into the air with wonderful violence, whilst the atmosphere is filled with the steam. The height of the columns varies from

THE GREAT GEYSER.

eighty to one hundred and eighty feet, and they succeed one another with great rapidity; the last being generally the most vigorous. The time between these appearances is small, and the eruptions are periodic, taking place about four times in twenty-four hours, but they are not strictly regular.

It is but a small step from these phenomena to those singular eruptions of mud which are observed by the naturalist, and which form a connecting link between the hot fountain and the volcano. The consistence as well as the composition of the material thrown out in these eruptions is not always the same. Sometimes mud mixed with stones and naphtha is expelled, while sulphurous vapour and hydrogen gas are disengaged. A remarkable instance of this kind of eruption occurred in the island of Sicily, in 1777. In the south of Europe, however, the products of eruption are chiefly solid matter—dry ashes, fluid rock, called lava, and scoriæ: these are generally accompanied by the emission of flame and smoke.

Volcanoes.—A volcano is a mountain of conical shape, composed, superficially at least, of strata sloping away from a central cup-shaped cavity, and giving out at its summit, with internal commotion, lava, stones, scoriæ, and aqueous vapour, with certain gases.

Volcanoes are, for the most part, of some height, and peaked, but this is not always the case; a number of small elevated hills being equally volcanic in their character with those of loftier height. All Europeans are familiar with the names of Mount Etna, in Sicily, and Vesuvius, in the Bay of Naples. The cruptions of the former have been very numerous, and their history is lost in antiquity; by those of the latter Herculaneum and Pompeii were overwhelmed.

Mount Hecla, in Iceland, must also be mentioned among the more considerable volcanoes of Europe, but several others of importance also exist in the same island.

The Greek Archipelago contains the islands of Santorin, and two smaller islands, which appear to have been heaved up by volcanic action from the bed of the sea, a belief which is favoured by authentic history. From these islands a volcanic chain extends to the eastern coast of the Peloponnesus, where several rocks of a decidedly volcanic character present themselves.

A far more imposing extent of volcanic agency awaits us on the continent of Asia. It is possible to trace a line of volcanic operations across the very centre of this vast tract of land, from the shores of the Caspian Sea—that is, from the Caucasian mountains—through Central Tartary, to the northern declivity of the Celestial mountains in the 43° of latitude. Within this range are some extinct volcanoes and their products, and others in a state of activity, abundantly proving the existence of volcanic agency for the distance of three thousand miles. In the Indian Archipelago a remarkably arranged volcanic region exists, in a form approaching to that of a horse-shoe, its N.E. extremity being a little beyond the 20° of N. latitude, and at the 120° of E. longitude. From this point it descends, passing in its course through the Philippine Islands, and, inclining to the east, it crosses the equator, and juts out from the east of the Celebes to New Guinea; from thence it takes a westerly direction, and, descending nearly to Timor, extends through the Moluccas to Java; then, bending northwards, it is prolonged through Sumatra, and terminates at Barren Island, in the Bay of Bengal.

On the opposite side of the globe is a large continuous chain of volcanic mountains, which commences on the coast of the Mexican Gulf. The first mountain in this remarkable chain is a small volcano called the Volcan de Tuxtula; then the high peaks of Orizaba and Popocatapetl; farther west lie the volcanoes of Jorullo. Some of these mountains are covered with perpetual snow. The whole chain extends to the length of one hundred and forty leagues.

The eruptions of volcanoes are usually accompanied with emission of flame; but this is not invariably the case. Some eruptions are not attended with any appearance of fire, while all burning mountains are not entitled to be considered volcanic. The eruption generally breaks out with violent noise and concussion of rocks. The force by which these movements are effected is most astonishing, and the diffusion of matter projected is often exceedingly extensive. When the material is of the lighter kind, it is often conveyed by its original momentum, added to the favouring influence of the wind, to a considerable distance. In September, 1845, an eruption took place in Iceland, and the ashes thrown out were, in ten hours afterwards, thickly deposited on some of the Scottish isles. These ashes had been conveyed through some upper current of air, and the original quantity must have been very large indeed. In an eruption of a mountain in South America, which took place ten years ago, ashes were thrown out in such abundance that the air was darkened, within a few minutes of the commencement of the eruption, even at a distance of fifty miles, so as to prevent recognition amongst the

inhabitants. Lava is only another condition of the ash, but it is thrown out in a liquid or fused state; and, generally speaking, those mountains which throw out lava do not afford ashes. In the year 1783, a terrible eruption took place in Iceland, during which a prodigious quantity of lava was thrown out, not from the crater of a volcano, but from its side; the molten torrent flowed slowly down the side of the mountain for forty-two days, during which time it had travelled fifty miles; it then branched off into two main streams, flowing towards the sea; one of them was forty, and the other fifty miles in length. Its depth varied in different parts, according to the surface of the country to which it adapted itself, ranging from one thousand to six hundred feet; and its greatest breadth measured fifteen miles. In its course, it completely obliterated a waterfall.

In some instances blocks of stone have been upheaved and projected to vast distances in some of the islands of South America. One block weighing 200 tons was thrown to a spot nine miles from the volcano from which it was expelled. Sometimes this power shows itself in another manner, and changes the level of a large tract of country. Thus, in the middle of the last century, a volcano was formed in the centre of the great table-land of Mexico, upon which occasion a tract of ground, from three to four square miles in extent, was heaved up in a convex form to the height of 550 feet, from which arose several conical hills, none less than 300 feet in height, and the highest of them, Jorullo, 1600 feet high. The upheaving here described was attended with great noise, lasting a long time; and the inhabitants of the town saw flames issue from the disturbed tract, after which the noise ceased. Two rivers were destroyed which had formerly run through this part of the country, and, instead of them, there are now two springs of boiling water. The formation of Monte Nuovo, in the neighbourhood of Naples, and of Monte Rossi, upon the side of Etna, are due to a like cause; from which, also, not only are mountains raised up, but extensive subsidences take place. In 1772 a great part of the Papándayang, a mountain in Java, was swallowed up; the inhabitants of its declivities were suddenly alarmed by tremendous noises in the earth, and before they had time to retire from the vicinity, the mountain began to subside, and soon disappeared. The area of this subsidence was no less than fifteen miles long and six broad. The cone of Etna has repeatedly fallen in and been reproduced. In 1537, and again in 1693, the summit of Vesuvius was reduced in height; while, in the eruption of October, 1822, upwards of eight hundred feet of the ancient cone of that volcano were carried away.

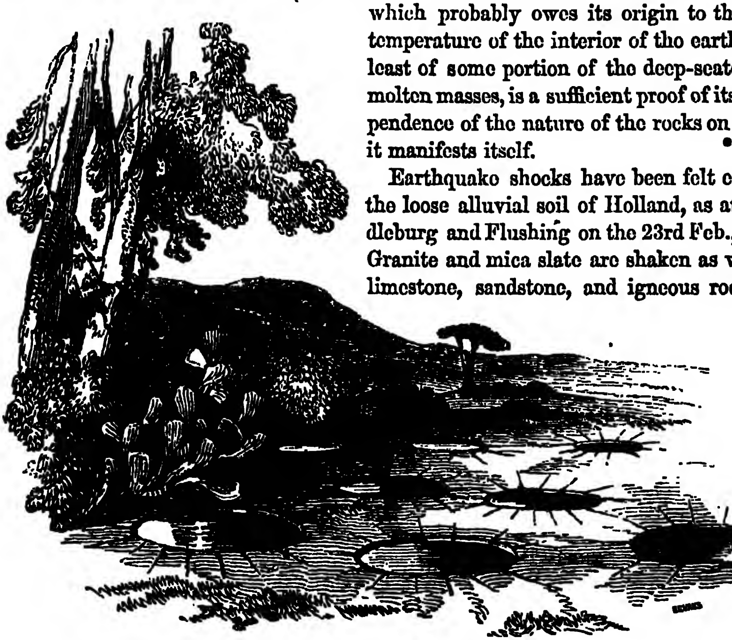

JORULLO, MEXICO.

Earthquakes.—The immediate effects of an earthquake are to crack and split the

surface in various directions; to make horizontal openings, as at Polistena; to change the level of the district, and to produce small discontinuities in the beds of the earth's crust. Sometimes a chain of hills is suddenly produced in a district before flat—an example of this kind having occurred at the mouth of the Indus in 1819. Sometimes a coast-line is permanently uplifted—sometimes a depression is caused; but on the whole, volcanic action seems rather to elevate than to depress, and thus tends to exaggerate the inequalities of level of the earth's crust.

If we could obtain daily intelligence of the condition of the whole surface of the earth, we should very probably arrive at the conviction that this surface is almost always shaking at some one point, and that it is incessantly affected by the reaction of the interior against the exterior. The frequency and universality of the phenomenon of earthquake action, which probably owes its origin to the high temperature of the interior of the earth, or at least of some portion of the deep-seated and molten masses, is a sufficient proof of its independence of the nature of the rocks on which it manifests itself.

Earthquake shocks have been felt even in the loose alluvial soil of Holland, as at Middleburg and Flushing on the 23rd Feb., 1828. Granite and mica slate are shaken as well as limestone, sandstone, and igneous rocks of



VIEW OF THE EFFECTS OF AN EARTHQUAKE AT POLISTENA.

modern date. It is not the chemical nature of the constituent particles, but the mechanical structure of the rocks which modifies the propagation of the shock, or of the wave which occasions it. Where such a wave proceeds in a regular course along a coast, or at the foot of, and parallel to the direction of a mountain chain, interruptions at certain points have sometimes been remarked, and continue for centuries, the undulation passing onward in the depths below, but never being felt at those points of the surface. The Peruvians say of these upper strata, which are never shaken, that they form a bridge. As the mountain chains themselves appear to have been elevated over fissures, it may be that the walls of these cavities favour the propagation of the undulations moving in their own direction; sometimes, however, the waves intersect several chains almost at right angles,—an example of which occurs in South America, where they cross both the littoral chain of Venezuela and the Sierra Parime.

In Asia shocks of earthquakes have been propagated from Lahore and the foot of the Himalayas (22nd January, 1832) across the chain of the Hindu Koosh, as far even as Bokhara. The range of the undulations is sometimes permanently extended, and this may be a consequence of a single earthquake of unusual violence. Since the destruction of Cumana (Central America), on the 14th December, 1797, and only since that epoch, every shock on the southern coast extends to the mica slate rocks of the peninsula of Marriquarey, situated opposite the chalk hills off the mainland. In the great alluvial valleys of the Mississippi, the Arkansas, and the Ohio, the progressive advance from south to north of the almost uninterrupted undulations of the ground, between 1811 and 1813, was very striking. It would seem as if subterranean obstacles were gradually overcome, and that the way being once opened, the undulatory movement is propagated through it on each occasion.

Change of Level of Land.—If we proceed from the study of the phenomena exhibited by active volcanoes and earthquakes to consider whether they are constant or periodical, and whether their return may be anticipated, calculated, or provided against, we soon find that, although within certain limits, and over very extensive areas, they exhibit a certain degree of regularity, yet that, on the whole, there is no possibility of determining how long an interval may elapse, or in what form the next effect of disturbing force may appear. Those volcanoes, indeed, whose immediate effect is smallest, are usually the most frequently in action; and the districts where earthquakes are almost daily phenomena are not more frequently destroyed in this way than those less immediately adjacent spots where such active violence is rare. Still there can be no doubt, from the general character of the facts now known and recorded, that there is, in many cases, a very deep-seated communication between volcanoes and volcanic districts, widely removed from each other. The earthquake of Lisbon was felt over an area four times as large as the whole of Europe; and the earthquake of Concepcion disturbed an area of nearly three hundred thousand square miles, permanently elevating an important proportion of the whole.

A very large part of the earth's crust is thus exposed to great and sudden changes, effected by mechanical violence, and incessantly bringing towards or above the surface some portion of the intensely-heated matter existing beneath it. That there must be a considerable pressure over a large proportion of the inner surface of this crust, and that it must exist in great measure in a state of tension, there can thus be no doubt whatever; and we must familiarize ourselves with this condition, and with the mechanical and chemical problems suggested by it, in order to appreciate fairly the actual present condition of our globe.

But when, in addition to these effects—small, indeed, in proportion to the whole surface, but not small in their general result—we consider other movements that are undoubtedly taking place on a far more extended scale, when we find that, where there is never, or very rarely, any earthquake movement, there may still be a constant change of level over the whole area of a vast continent, we shall be in a still better position to appreciate the full extent of those modifications, which it requires, not merely years, but centuries, to render distinctly manifest to the eyes of man.

In such cases, however, the difficulty of perceiving the change is rather a mark of its magnitude and importance than a reason for its being left out of consideration. The greatest changes are those—not of a day or a year—but those which take centuries, or even thousands of years, to accomplish.

Tens of thousands of years must pass away ere some of those other strictly-periodical movements are concluded, whose nature we know, and whose rate we measure; and which serve to bind, not our earth only, but the system of planets to which we belong, to the other bodies and systems of similar kind in the universe.

No less considerable, perhaps, is the time required to complete some great period in the earth's own history. This, at least, is the natural conclusion to which we arrive by the study of existing nature; and it is a conclusion fully borne out by every result of observation with regard to the past, and every principle of analogy presented in the sciences most nearly allied.

Not only may we trace the result of subterraneous action, as exhibited on a grand scale in earthquakes and associated with volcanic phenomena, but also in many parts of the world where such indications of destructive violence are rarely or never exhibited. Among the more remarkable instances of this kind may be quoted the numerous raised beaches on our own coast, and along the greater part of the north-western portion of Europe—the occasional submarine forests observable, often in the immediate neighbourhood of the elevated tracts, and the singular instances in the Eastern Archipelago, and the coast of South America, of very large tracts of country, extending hundreds and even thousands of miles, undergoing, it would seem, a slow but continual change of level, in the one case consisting, on the whole, of elevation, and in the other of depression.

The evidence of movements of this kind is very complete, especially with reference to long periods of time marking geological epochs.

In England the whole of the south and west coast exhibits, at intervals, distinct marks of elevation, alternating sometimes with depression, the elevation amounting to from a few to about sixty feet above the present high-water mark. It will readily be understood that, in consequence of movements of this extent, there is occasionally laid bare not only an ancient sea-beach, but the former bed of a sea, and in fact raised sea-bottoms, analogous to the ancient beaches, are well-marked phenomena, not unfrequently exhibited.

When we consider the facts thus brought to light by an examination of existing sea-coasts, and find marks of change, effected, it would seem, within a comparatively recent period, it is scarcely possible that we should not be struck by the fact, that while all seems still and unchanged, these not inconsiderable movements may be modifying all the various conditions of organic existence in these parts of the globe. For it is no unimportant fact that the general level of a country is raised or depressed from its former condition. The drainage, the temperature, the quantity of rain that falls, and other important matters, are all affected by such change; and when the alteration extends to the whole coast-line of an island, it is only reasonable to conclude that the whole surface of the island is more or less acted on, although, from the extreme slowness of the change, it cannot be measured by any of the ordinary means available.

On a line of coast easily eroded by the action of the waves, and in a district in which cultivation soon destroys every vestige that may have been left at a distance from the shore, these difficulties are even greater, and can hardly be so far surmounted as to allow us to obtain exact results. But when we can examine carefully, and by actual measurement, localities removed some distance from the coast, we then may obtain certain knowledge both as to the amount of the elevation and the direction of the elevatory force. An opportunity of this kind is offered on the north-western coast of Europe, where the deep and narrow inlets called fjords, so characteristic of the

shores of Norway, have allowed observations to be made more direct and decisive than any others of the kind hitherto recorded.

It there appears that the south-east coast of Norway has been elevated about two hundred yards within a comparatively recent period; that the whole coast, up to Cape North, has also undergone elevation, though not to quite so great an extent; that this elevation is nearly equal over considerable tracts, the lines of ancient sea level (which can be clearly traced) being very nearly horizontal, and gradually dying away towards the interior of the country.

Depression of Land.—In singular contrast with observations of this kind on land near the arctic circle, and illustrating similar important changes on a very grand scale, we come next to the consideration of a vast multitude of islands in the great Eastern Archipelago, and elsewhere in the tropical seas, surrounded and apparently formed by solid material, secreted by a minute animal, the coral polyp.

BLOCKS OF CORAL.

It would seem that nothing is more striking or picturesque in the warm seas near the Equator than the coral islands, of various kinds, that abound in certain parts, but are never seen in others. They are of three kinds: *fringing* the sides of considerable islands, and having a manifest foundation in the land adjoining; forming, as it were, *barriers* of coral detached from the land and having an intervening shallow basin between the outer reef and the island; and entirely detached from the land, forming circlets of coral reef, with a basin or lagoon included—these latter being called lagoon-islands, *atolls*.

The circumstances under which the coral animal builds its singular habitations on a large scale are very well known and clearly limited. The animal cannot live at a greater depth than twenty to thirty fathoms; but great masses are found, *in situ*, at a far greater depth than this. The only explanation is, either that the waters of the sea have greatly risen in some particular parts of the ocean—a manifest absurdity —or that the land on which these corals first grew has sunk down just as the land in North-western Europe is rising. A coral reef, consisting of a fringe of live coral attached at a moderate depth, is the simplest phenomenon of the kind, and is easily understood. This is called a fringing reef; and as the animal only grows vigorously when much exposed to the beating of the waves, the limit of its extension is easily determined. But if this whole island now sinks down slowly, the lowest part of its coral will gradually die, and new portions rise still to low water. Owing to the comparative shelter within the circle, there is, however, a very shallow basin formed between the outer edge and

the land. In this state it is called a barrier reef, and one or more islands will be surrounded, perhaps at some distance, by this singular shelter.

If the barrier reef sinks still further, it becomes at last an atoll.

The result of the investigations on this subject is, that where these atolls and

DEAN'S ISLAND.

barrier-reefs exist, there has been long-continued subsidence within a comparatively recent period. In this condition are several large tracts in the tropics, parallel to, but removed some distance from, other tracts in which we have evidence of recent elevation. Perhaps the most remarkable area of depression is that including the Caroline and the Low Archipelagos, extending nearly eight thousand miles, with a breadth of about two thousand five hundred miles.

There has been, therefore, in this wide tract, now only occupied by islands, scarcely seen above the sea-level, and in part kept in existence by the continual labour of the coral animal, an ancient tropical continent, rivalling the two Americas in magnitude, and greatly modifying the temperature and climate of that part of the world in which the change has taken place.

Such is the evidence on which we assume that there are districts of the earth now undergoing depression on a scale not dissimilar to nor indeed unconnected with that on which we recognise elevation. By observations of this kind on low islets, which now only retain their existence owing to their having been found convenient for the habitation and structures of the coral animal, we are enabled to recognise the last vestiges of lofty peaks, which once, perhaps, existed as mountains penetrating the region of the clouds. We may thus reconstruct in imagination the land which has been submerged, and may even be induced to speculate concerning the date of the submergence, and the plants and animals that clothed the ancient continent.

Considered in their extent and in their bearing on the general argument, these various facts and probabilities with respect to disturbance of the earth's crust suggest conclusions in the highest degree important and interesting. We have seen, for instance, that the solid framework of our globe is frequently exposed to the action of subterranean forces; obtaining relief from time to time by volcanic outbursts of melted rock and ashes, thrust forth from beneath with almost inconceivable force and velocity—and occasionally tearing asunder the thin crust that has cooled over the boiling and restless mass beneath, producing undulations and earth-waves which embrace in their vibrations a large proportion of the surface, which carry terror with them, and leave destruction behind them. We have seen, also, that besides movements of this kind, readily and immediately perceived, there are others, affecting areas no less extensive, and in a still greater and more permanent manner; modifying the form of land, producing or destroying continents and islands, and effecting changes which, in their turn, influence the conditions of life upon the earth.

Changes of this kind—so considerable that it is difficult fully to realize their amount, so majestic in their progress that the age of man is hardly an appreciable instant in reference to the time they occupy, so directly influencing the great physical features of the earth that our speculations with regard to them carry us back to an early period

of its existence—will at once be recognised as of the most vital importance in reference to the continuous and ancient history of our globe.

And the facts thus learnt harmonize perfectly with other phenomena of nature, for they speak of the existing condition of things as incidental and not permanent—as a part, and a very small part, of a mighty and continuous whole. • •

They remind us, also, that if we study nature we must everywhere, and at all times, expect modification and change. The ideas of matter and motion are seen to be inseparable, and no rational conclusions can be arrived at without bearing this truth constantly in mind.

Aqueous Action.—Bearing in mind the actual configuration of the globe, the relations of the land and water which form its surface, and the extent to which elevavation and depression are going on, let us next consider the changes that are produced by those agents which are in the ordinary sense of the word natural, as not surpassing the every-day operations of nature.

Such alterations, so far as they are manifest, are of three kinds: including, first, those brought about by the agency of life in all its forms; secondly, those simply mechanical, effected by rain and other atmospheric causes, by rivers in their course to the sea, by marine currents, by the action of the tides, by occasional storms and by floods, by the transport of icebergs, &c., in addition to ordinary volcanic and earthquake results, eruptions of lava and other solid matter, and the slow upheaval of large tracts of land unaccompanied by violence; and lastly, the changes produced by the action of magnetic currents passing through the crust of the earth, and effecting their results also during the lapse of time, assisted, perhaps, by the mechanical displacements and evolutions of heat derived from volcanic influences.

The changes effected upon the earth's surface by mechanical agency are very much greater in every respect than could readily be believed without actual calculation. Every shower of rain that falls in a mountain district washes down some particles from the solid rock; every winter frost detaches multitudes of larger fragments; every occasional storm produces likewise its effects. All these particles of matter, some in the form of impalpable mud, others in larger particles, and others in the shape of gravel and blocks of stone, are carried down the steep gullies and river courses towards the plains, and thence onwards to the ocean; and unless they are first intercepted by extensive lakes, the matter brought from the high grounds is thus carried on, till the water, losing its rapidity of motion, loses also its power of conveying substances heavier than itself, and the mud is deposited either in the bed of the ocean or at the mouth of the river, according as the river current is sufficient or not to make head against the tidal changes of the open sea. One or two instances of each kind of the termination of river courses, will give a sufficient idea of the nature of these operations.

The river Ganges, with its confluent the Burrampooter, empties itself into the sea, at the head of the great Bay of Bengal, by a vast multitude of small channels. These commence to branch off from the main stream at a distance of about 220 miles from the sea, and form a triangular area, whose base at the Bay of Bengal is about 200 miles long.

The whole area of upwards of 20,000 square miles thus inclosed forms what is called from its shape a *delta*, and it is found on examining this delta that the whole mass, to a great depth, consists of the mud and other matter brought down by the river in the course of ages.

Now it may seem almost extravagant to assume, from any superficial observations, that 20,000 square miles of solid land could be by any possibility deposited by a river

at its mouth. But no one will doubt that whatever may be the rate of the river current, it cannot but be greatly checked by passing through these hundreds of narrow channels, and must therefore deposit in them a very large quantity of the heavier mud it conveys. It has been calculated by Major Rennel that during the flood season as much as 450 millions of tons weight of mud are brought down daily by the rivers in question, and either deposited in the different branches, or increase the size of the delta by encroaching yet further on the Bay of Bengal. It will perhaps assist the reader in forming an idea of this quantity, to state that it is equal to about a hundred times the mass of the great Pyramid of Egypt, and that if the deposit were to go on daily at this rate for half a century, there would be a quantity of matter equivalent to a stratum a yard thick over the whole 20,000 square miles of the delta.

When the current of the river, as it empties itself into the ocean, is so powerful as to proceed onwards in spite of the tides and marine currents, a different result is produced. The mighty river of the Amazon, in South America, is a remarkable instance of this, for this stream, loaded with mud and heavy detritus, may be distinguished from the pure water of the sea at a distance of three hundred miles from land. A vast tract of swamp is formed along the coast in the direction of the marine current by this mud, and the shallow sea along that coast is rapidly being converted into land.

Rivers, under ordinary conditions, thus bring down and deposit at their mouths, or in the lakes through which their waters pass, very large quantities of solid matter; but the occasional freshets and the floods that are common in all mountain districts produce yet more striking effects, and frequently remove fragments of rock and large quantities of earthy matter. Even in Scotland instances are not rare of floods of water carrying away bridges and moving fragments of rock of many tons weight, and the effects in the Alps and other loftier chains in temperate and cold regions are very much greater. Within the last few years, owing to some cause probably connected with the melting of snows in the Andes, the inhabitants of a district in New Granada, almost under the equinoctial line, about 4° N. lat., were almost all destroyed, and their houses carried away by a torrent of mud, stones, and gravel, the amount of which is calculated to have exceeded 250 millions of tons weight.

Glaciers are also mighty agents of change. It is well known that high mountains in all parts of the world are constantly covered with snow, their temperature even during summer not rising sufficiently to melt away this covering. Even in the tropics we may rise from the most intense heats of summer through every gradation of season to perpetual winter. At the equator the line at which the snow never melts is about 16,000 feet above the sea. In the Swiss Alps it has diminished to about 8700 feet, and still nearer the artic circle it descends still lower, until at length it reaches to the very sea level.

Snow-clad mountains are not glaciers, nor do glaciers belong exclusively to the snowy region. The common form of a glacier is a river of frozen snow, having its origin in the ramifications of the higher valleys. It is the outlet of some of the vast reservoirs of snow, being a prolongation of the winter-world above, often protruded into the midst of warm slopes, and even to the borders of cultivation. It moves on like a river, with a steady flow, and though no eye can trace its motion it is pressed onwards perpetually, and its termination, apparently an immoveable crystal wall, is in fact perpetually changing—a stationary form of which the substance wastes—a thing permanent in the act of dissolution.

For the greater part of its course a glacier is usually covered with blocks of stones,

which are borne upon its surface. These, which are often of vast dimensions, are split off from the peaks of the higher mountains, and by the expansion of water in cooling fall from the cliffs which bound the sides of the glacier during the middle part of its

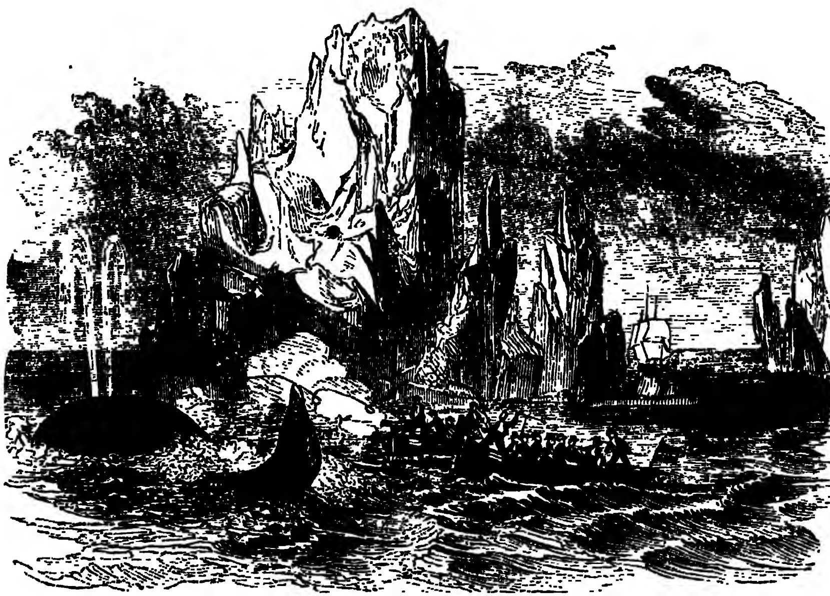
GLACIER OF THE RHONE.

course. They may be used to trace the rate of motion of the torrent, and are seen from year to year descending with it, the glacier becoming burdened with a constantly increasing charge, and at length depositing these rocky fragments at its final extremity. It is chiefly from the fact that it conveys these fragments to a distance, and there forms a superficial deposit of a very remarkable kind, that the glaciers are objects of interest to the geologist, and play an important part among the agents of change on the earth's surface. Their lower parts are sometimes completely darkened with the quantity of rocks which are in the act of being transported to a distant locality, and the dimensions of these rocks vary exceedingly, including some fragments measuring hundreds of thousands of cubic feet, and innumerable others of smaller size.

Icebergs.—In a country like Switzerland, and under present conditions of temperature, the extreme effect of glacier motion is to deposit stones and gravel on the sides and near the termination of some of the valleys of the higher mountains; but it would appear from the examination of the opposite mountain of the Jura (distant about fifty miles) that their effects were not always so limited but that the stream of stones was formerly carried across the great valley of Switzerland. Whatever the cause of this may be, there is no doubt that in more northern climates these icy mountains frequently come down into the ocean, and are often broken off and floated away by marine currents. The number of icebergs—as they are called when in this state—annually floated off from the Arctic Seas into southern latitudes, is far greater than could be imagined, since as many as five hundred have been counted in view at one time in latitude 70° N., while a considerable number are conveyed more than 20° south of that latitude before they are melted.

The fragments of ice thus distributed over the Atlantic Ocean, and generally, no doubt, in nearly the same course, in consequence of the prevalent currents, cannot but produce a considerable effect in forming deposits on the sea-bottom. Icebergs are of various

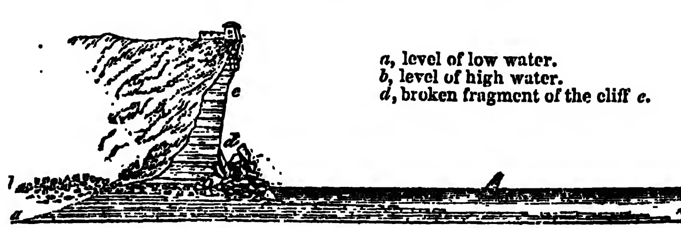
dimensions—some extremely large, and loaded with great blocks. Whatever size they may possess above water, there must be a mass enormously greater below, since for



ICEBERGS.

every cubic foot visible there must be at least eight cubic feet out of sight. When, therefore, we are told of islands of ice two miles in circumference and one hundred and fifty feet high, we need not be astonished at learning that they have been found stranded in water fifteen hundred feet deep. The effect of the stranding of such enormous masses, and the quantity of gravel and blocks of stone deposited at the sea-bottom during the melting, it is scarcely possible to imagine.

Action of the Sea.—Marine currents daily wear away portions of the coast washed by them, some of the results of which are seen in the chalk cliffs of the Isle of Wight



EFFECT OF TIDAL ACTION ON A COAST.

and of Normandy, while on a grander scale the same process is going on in the north of Scotland, where the sea has cut for itself a passage through cliffs of the hardest porphyry, separating islands from the main-land, and tearing these islands to shreds, until at last even these are washed away, victims to the resistless violence of moving water.

The preceding diagram well illustrates the tidal action on a cliff in the Isle of Oleron in France.

The extent of solid matter deposited in new places by the action of water is exceedingly great, and really produces a very considerable change in the lapse of centuries. But there is another kind of action also going on on our globe, which, although of a directly opposite nature, is not less effectual. The numerous volcanoes and centres of volcanic eruption distributed, as has been already described, over the earth's surface, pour out melted rock and various heated substances upon the surface, and produce strange and unexpected additions to the solid matter of the globe.

Such outlines as have been given may serve to communicate a notion of the intensity and power of the forces now in action, and a careful study of them will greatly assist in obtaining distinct ideas regarding geological changes. And this is the case, because whatever may be the difference of degree and intensity with regard to the causes that have produced the appearances recorded by geologists, there can be no doubt that the only true and sound basis for all speculations concerning them should be a consideration of what is now going on in any analogous mode. It will soon appear, when we begin to study the facts of Geology, that these are, to a great extent, due to causes so similar that we can scarcely distinguish between them; for the strata, and disturbances of strata, present very nearly the same appearances as those now in course of deposit, or now being disturbed by the forces just described.

Organic Influence.—But we must not leave out of view another very marked agent in modifying the earth's crust—namely, that which is connected with organic existence. In the vegetable world, and in tropical countries, the results thus produced both on land and at river mouths are very important; for we find vast tropical forests sometimes changed by slight disturbances of level into swamps, while at other times the trees are carried away by floods and deposited in river beds, or conveyed down to the open sea. Other and not less important modifications are also effected by plants of small size producing peat.

But it is animals of low organization that affect in the most striking manner the actual solid substance of the earth—their skeletons occasionally forming extensive and thick beds, and the living individuals and groups building up whole mountain masses, compared with which the most mighty and magnificent of human labours shrink into insignificance. Among these, the polyp which forms coral islands, the yet less manifest foraminifera, and the minute and almost invisible infusorial animalcules are remarkable instances; and certainly it is calculated to stagger the faith of any one when he hears, for the first time, that masses of rock, many leagues in extent, are founded in the depths of the ocean, and that these are built up to the height of hundreds of feet, by minute, frail, and gelatinous animalcules. The prodigious extent, indeed, of the combined and unintermitting labours of these little world architects must be witnessed in order to be adequately conceived or realized. They have built up a barrier reef along the shores of New Caledonia for a length of four hundred miles, and another which runs for one thousand miles along the east coast of Australia. They form also circular rings or islands rising out of the deep water, an account of one of which may be given as an example of their labours. Those of small size measure fifty miles in length by twenty in breadth, so that if the ledge of coral were extended in one line, it would reach one hundred and twenty miles in length. Assuming such a ledge of coral to be a quarter of a mile broad and one hundred and fifty feet deep, we have here a mound compared with which the walls of Babylon,

the great wall of China, or the pyramids of Egypt are but children's toys; and it is built amidst the waves of the ocean, and in defiance of its storms, which sweep away the more solid works of man.

But animals infinitely more minute, and apparently more helpless, than these coral polyps also form important deposits on the earth's surface. Certain kinds of siliceous stone used in polishing metals, and known under the name of Tripoli and Polishing slate, are entirely composed of the siliceous cases of the infusorial animalcules, and at one spot in Bohemia there is a single stratum of this substance not less than fourteen feet thick, every cubic inch of which has been estimated to contain the flinty skeleton of more than forty thousand millions of individuals.

Thus, then, it appears that there are constantly going on great and important changes of the physical features of the globe, even so great as to affect the relative distribution of land and water, and that these changes are produced partly by the transporting power of water and by the aid of frost; partly also by the upheaving and ejecting of matter by volcanic agency; and partly, too, by means of the ceaseless labours of organized beings, some of them so minute that they cannot be appreciated by the unassisted eye.

Recapitulation.—It may be worth while now to bring back the reader's attention to the mode in which the various facts and deductions of the science have been presented, and the object which it has been endeavoured to keep constantly in view.

Nature—understanding by that term the conditions under which matter and motion are presented to the human intellect by the agency of the external senses—Nature is everywhere before us, and, whether we will or not, must produce a certain effect upon us. We may study or not the various departments involved in the simple observation of external nature—we may reflect upon or neglect the contemplation of that beautiful and invariable harmony which reigns throughout in the laws and methods according to which matter is arranged—we may be exclusive in our devotion to a special subject, or we may wander discursively over all—in a word, we may be as regardless or as enthusiastic as we will, but we cannot escape being influenced and affected by every law and every modification of it. Thus it is that the study of Nature is a personal matter, and in some form or other is the source of all our purest, best, and most lasting enjoyments. It has been endeavoured to illustrate the subject of Physical Geography by familiar examples, proving the great principle of mutual adaptation and mutual relation everywhere present, and to show that nature is one—governed everywhere by the same laws, following everywhere and always the same plan, and producing that very harmonious variety which is so essential for our appreciation of beauty by the necessary and invariable action of a few simple and easily understood arrangements.

For this purpose, those general facts relating to our planet were first brought under notice which connect the earth with a great and wide system, extending indefinitely in space, and not limited by any boundary that we can even imagine. All these various and innumerable spheres move in perfect harmony, each in its accustomed course, not uninfluenced by the rest, nor without influence upon them, but not interfering, and exhibiting no elements of discord. We then proceeded to consider the action of the imponderable agent which we call *heat*, in consequence of whose influence that portion of matter belonging to us as a planet exists on the surface in the three conditions of earth, air, and water; these conditions not being necessary to matter, and only having distinct reference to the organic bodies presented at and near the earth's surface. The effects produced by the mutual action of earth, air, and water, were then dwelt

upon, and we considered the results of long-continued action of that kind in elaborating the existing state of the surface. Each of these so-called "elements" was the subject of special consideration, and the most important phenomena of each came successively under our notice. In all these cases the important conclusion was that which connected the one set of facts with the other—the apparent and proximate cause with the observed effect.

Having thus studied the various phenomena of external nature dependent on the conditions of matter, and visible to every one, we adverted to the fact that besides this kind of mutual action there is also another and more palpable change produced by mechanical violence, and acting at least partially through the agency of heat. Earth, air, fire, and water, however chemists may regard them, and whatever we may know of their ultimate components, are thus in one sense true elements—for Nature acts by them, and with reference to the conditions of matter as involved in their existence. A system of movements was next brought under discussion, which appears to be going on in the earth's crust on a grand scale and requiring the lapse of long periods of time, and it was seen that the various periodic changes effected, whether diurnally by the earth's revolution on its axis, and by oceanic and atmospheric tides—monthly, according to the relative actions of the moon and the sun on the ocean—seasonally, according to the position of various parts of the earth presented to the sun—annually, owing to the earth's revolution round the sun—in many years or centuries from recurring positions of the planets; that all these are but types, as it were, of still greater but also periodical changes, of which, in many centuries, only a very small part can be recognised. Thus it appears that inorganic nature is everywhere and always changing—that matter and motion are inseparable ideas.

And now, lastly, it is evident from the study of the earth's surface, as well as from various phenomena presented immediately beneath the surface, that the methods at present adopted in the distribution of life in horizontal extension are the same as those according to which animals and vegetables have succeeded each other in time.

Here, as before, the law is the same—the result analogous; but still the lapse of time is indicated, the centuries that have rolled by have stamped their mark upon all forms of matter belonging to them; the period, whatever it may have been, during which certain operations were performed, and certain results produced, was individualized—if one may so say—and thus having a characteristic, it may be identified and distinguished from other periods during which similar but not the same results were brought out.

Thus it is that the study of Physical Geography leads to a knowledge of the true principles of Geology. And the great results of geological investigation are also simple, and may be stated in few words. The materials of the earth's crust are arranged in definite order, and they contain the remains of the animals and vegetables that lived during their formation. Hence we connect Descriptive Geology with the history of the earth and its inhabitants.

In concluding this part of the subject, it may be advisable to recapitulate the general results of investigation concerning the earth as a planet. Its form being very nearly that which would be assumed by a fluid body, revolving in space and subject to the law of gravitation, it has been assumed that the compressed spheroidal shape is an argument tending to prove that the earth was originally in a state of igneous fusion, from which it has cooled down by radiation in passing through a cold medium. No one, however, has explained where this lost heat has strayed to.

It has been suggested that, supposing the whole mass to have first existed in a gaseous state, like a thin mist, in consequence of intense heat, such a gaseous nebula would first become fluid by cooling, and afterwards a film of oxidized material would form on its surface, which in time contracting, cracking, re-hardening, and thickening, might become such a film as that we now see. Whether this view may be possible in a chemical sense, or whether there is any good reason to assume it mechanically, one thing should not be forgotten—namely, that the shape would be equally assumed by a solid sphere having as much elasticity as the least elastic of the materials which form the earth's crust.

That the density of the whole mass of the earth is not very much greater than the density of the surface, has likewise been put forward as an argument in favour of this igneous theory of the earth's origin; but here again it must be remembered that there are many ways of explaining this, as there are also of accounting for an increasing temperature within moderate depths. That there is a very considerable quantity of intensely heated matter at no great distance beneath the surface, and communicating readily at distant points, the phenomena of earthquakes and volcanoes place beyond a doubt, but with regard to the actual state of the internal nucleus there do not seem to be at present sufficient grounds for coming even to any proximate conclusion.

The magnetic condition of the earth's surface, and the remarkable results of recent discoveries on this subject, must no doubt have very important reference to a large class of phenomena connected with igneous rocks, with the numerous veins and fissures in them and in adjacent rocks, and with the filling up of these with minerals or metallic ores. The manifestly gradual and successive nature of this filling of metalliferous veins chiefly in certain directions seems partly accounted for by the nature of the currents and their magnetic directions; and if, as is most likely, currents of magnetic force are related to or productive of changes in temperature, a very important field is open for investigation and speculation in a department of Geology, as well as Physical Geography, not less interesting than it is practically important.

This view of the earth as a planet—as a mass of mixed material constantly in motion, exposed to various influences, and subject to much internal change—suggests many problems of deep and lasting interest in other departments of science. If these magnetic currents steadily pass on with never-ceasing motion through the whole external crust of the earth, we are justified in considering them in their relations to the forms of matter in general, and it will be at once seen how important these relations may be. Minerals, though not endowed with life, tend to assume definite forms; rock masses also assume forms in some respects similar; minerals, in their perfect state, are crystals; and crystals are the different simple bodies and natural definite compounds presented in the shape which they invariably assume when not interfered with by external influences, and permitted either to become solid or to arrange themselves in their natural order when solid. But the properties of crystals are intimately connected with and related to light, heat, electricity in its ordinary form, magnetism, and chemical action; and thus we find the magnetic condition of the earth's crust directly connected with the conditions of matter within the surface.

In thus venturing to point to the direction in which modern discoveries and modern speculations will naturally be directed in order to enlarge the boundaries of general knowledge, we are by no means departing from the strict subject-matter to which we are limited. These matters do, all of them, and in the highest sense, belong to Physical Geography, and by that science they are understood and applied. Physical Geography

includes them, consists of them, they form the elements of the most important general views on the subject, and they are thus directly connected with the most interesting and valuable of the elementary facts on which Geology, as a department of Natural History, is based. No apology is therefore needed for apparently travelling out of what may seem the direct path of the subject; as, if the reader can be induced to make but a little progress, and consider the subject in the light in which it is here placed, he will not complain that it wants interest, or is beyond the comprehension of any intelligent and thinking person.

DESCRIPTIVE GEOLOGY.

Introduction.—When we pass from the consideration of Physical Geography, properly so called, and endeavour to picture to ourselves what may be the result of those various operations now in progress tending to produce change in the nature or appearance of the earth's crust, we at once enter on speculations which may be called geological; for it is the object of Geology to learn what may have been the mode of action in past time by evidence now offered concerning present modifications.

The application of Physical Geography to a study of geological causation is thus a short and easy step, and indeed it only involves the additional study of the effect produced during long periods of time, and the probable changes thus involved, in order that we may enter on the consideration of some of the most interesting geological problems.

A very superficial examination of the earth's surface offers sufficient proof that there is a certain degree of order in the arrangement of the materials, and that there are indications of system and plan somewhat resembling that periodical recurrence of days, months, and seasons which must have first suggested to men the investigation of the cause and the existence of a law in reference to the heavenly bodies. Any intelligent observer discovering order in the arrangement of the materials of the earth's surface in one place, and comparing it with the arrangement elsewhere, finds that the two do to a certain extent correspond. In this way it is made out by observation, that there are a number of beds, or similar collections of sand, mud, and stone, which, owing to some peculiarity of appearance or contents, may be identified. This is the first step in Geology, and the knowledge of this fact soon leads to the more strict investigation of the nature of the deposits thus noticed, and ultimately brings to light a vast multitude of interesting facts, all showing that there is abundant regularity in the earth's structure, and many of them pointing very clearly to some definite order and system, which, after a succession of observations, is at length found out to agree with some definite system. As the astronomer deals with space, so does the geologist with time, and in both sciences multiplied observations add constantly new facts; the contemplation of facts suggests the existence of laws, and the laws, being once fairly made out, are applied to practical purposes.

Geology, then, is a science of observation, the object of which is to investigate the nature and to discover the order of arrangement of the materials of which that part of the surface of the earth exposed to observation is made up. It has to deal with

matters relating to what is generally called "the earth's crust." It has to determine, as far as possible, the complete history of this surface, and should do so by simple inductive reasoning, applied to the observed facts, whatever they may be. The first thing to be done by the geologist is to observe—that is, to acquire a knowledge of the true condition of the earth's surface; and this effected, he must endeavour to make out by what possible laws or regular processes such a series of appearances might be produced, and he must consider how far his observations justify him in assuming systematic regularity and a distinct order of recurrence, and how far they involve apparent exceptions to any assumed rules. It is not till he has learnt something of the cause as well as the effect that he can be in a condition to apply his knowledge to practice; but having been thus far taught, he will soon find abundance of opportunity for rendering it useful, whether to the agriculturist or architect, whose business lies with soils and materials for construction obtained from near the earth's surface, or to the miner whose object it is to penetrate its deep recesses for the sake of the metalliferous minerals to be obtained by mining processes.

But no such useful results can be obtained by a mere knowledge of what other people have found out. Observations must be looked upon as the food of science—food that must be digested before it is assimilated, and that can only be ultimately available for any useful purpose when thus digested and assimilated, for then only is it capable of producing new results, and forming an integral part of the intellectual constitution. Thus all facts must be classified, understood, and registered systematically; and we must have been able to deduce laws from their consideration before we can safely apply them to any practical purposes.

But although people generally are willing to admit the truth of this in cases where they perceive the results, and where the bearing of science upon matters of fact has been too long seen to be questionable, they are by no means so reasonable in the case of a pursuit like Geology, which is, to a great extent, new to them, and which is often looked on rather as an amusement than a study. It has thus sometimes been thought advisable to commence by directing attention to results, to show what has been done and what may be done for the actual benefit of mankind by the knowledge of geological facts and the application of geological theory, and to illustrate the importance of the subject by exhibiting the intimate relation of this science with others of acknowledged value, such as Astronomy, Physical Geography, Chemistry, and general Natural History. Some of these relations have been already considered, and others will be alluded to in the following pages; but it is needless to go twice over the same ground, and anticipate matter which more fitly finds a place elsewhere. Still it must be admitted, that in order to understand Geology, and study it properly, we require to know, first, the general condition of the earth's surface, and the operations now going on upon the surface, tending to modify or alter it. We must know, secondly, the actual nature of the materials or mineral substances which make up the earth's crust, and which are found in it, and their relations with the existing surface. We must know, in the third place, the mode of arrangement of the materials, the laws that govern that arrangement, and the action of those laws in ancient times; and, partly in order to recognise the true nature of such laws, partly because such objects are so commonly present as actually to form a very sensible part of the solid matter under examination, we must, in the fourth place, learn the true history of those animals and vegetables whose remains occur in or form the beds, and this we must do by connecting the natural history of existing animals and vegetables with that of the groups presented in the way just

described. The first of these four departments of Geology has been already discussed under the name of Physical Geography; the second is called Mineralogy, and is the subject of a separate treatise; the third is Descriptive Geology, in the usual acceptation of that term, which is now about to occupy our attention; while the fourth is frequently spoken of as Palæontology, but must be considered in connection with Descriptive Geology, on which it very directly bears.

Rocks.—In a geological and technical sense all masses of solid matter possessing a common character, and any degree of unity as a combined set of materials, are called *rocks*. In this sense, not only granite, slate, and hard sandstones and limestones, but the softest clays and even mud, and the least perfectly aggregated and loosest sands, are all spoken of under the same general term, and are all considered as sufficiently designated by it.

The form and method of aggregation differ, however, very greatly, and admit of a separation of rocks into three classes; for while we find some manifestly of mechanical origin, and bearing all the marks of deposition from water, arranged too into beds, as if from intervals or changes in the rate of deposition, others are as manifestly not referrible to such an origin, but have been affected by heat, and some have evidently cooled down from igneous fusion. A third class exists, intermediate in character between these two; for while the rocks in this case bear marks of original aqueous origin, and clearly exhibit proof of having undergone subsequent change, in many cases there is no reason for attributing this change to the action of heat. The first class are called by the geologist *aqueous*, the second *igneous*, and the third *metamorphic*.

Rocks that are called igneous generally exhibit some marks of general uniformity of structure without much approach to true stratification or superposition of beds of similar materials. Thus in granite we find crystals of quartz, felspar, and mica, mingled together without a base; and it is manifest that the process by which this arrangement of the parts took place was to a certain extent chemical and not mechanical, and might be accurately repeated at any future time on a mass similarly constituted, or any number of times on the same mass without change. On the other hand, a series of laminæ, forming a distinct bed of any kind, can generally be traced very clearly to the gradual mechanical process of deposition, and it is exceedingly unlikely that such a process should be accurately repeated in all its details, so as to produce a second time a series of strata which it would be impossible, on close examination, to mistake for the other. This is the case even when no organic remains exist by which the bed can be characterized, and in this respect there is a well-marked difference rarely to be mistaken. We have thus a manifest ground for the subdivision of rocks into two classes, determined chiefly, if not entirely, by the mechanical arrangement of the particles or the component parts, and by the fact of stratification being distinctly traceable, or the contrary. The one class, therefore, is called *stratified*, the other *unstratified*.

But again, there are two kinds of stratified rocks; for while sometimes the rocks remain very much in the condition in which they were deposited, or only altered by consolidation, the infiltration of some mineral substance into cavities, or the segregation of particles of the same kind, others have received, as it were, a new internal structure, superimposed on and sometimes obscuring, but not obliterating, the original one, and appearing to indicate that fire as well as water has been an agent in producing them.

We thus have a third class of rocks, mechanically and chemically distinguished

from each of the other two; and this third class, amongst which slates of all kinds, marble, &c., hold the most prominent place, is called *metamorphic*.

Names of Rocks.—With regard to the structure of rocks, there are some expressions, commonly used in geology, that require, perhaps, a word of explanation. *Porphyry* is one of these. It is a name applied when one of the constituent parts of a rock is disseminated through a basis in the form of grains or crystals. In those cases, however, in which the crystals or grains do not appear to be of contemporaneous origin with the base, the name porphyry is not properly applied. Such rocks are *conglomerates*, or *pudding-stones*. *Amygdaloid* is another term in common use in geology, and is used to designate rocks in which vesicular, almond-shaped cavities are dispersed throughout, these cavities being either empty, encrusted, half filled, or completely filled. The minerals that usually occur in these vesicles are lithomarge, zeolite, chalcedony, agate, heavy spar, or calc spar.

Structure.—The structure formed by the immediate aggregation of different species of minerals in grains and imperfect crystals, and without a definite base, is sometimes spoken of as porphyritic, but has also been called granular.

Granite is an example of this structure, but when, as happens occasionally, large and distinct crystals, whether of quartz, felspar, or mica, are distributed through granitic rocks, they become porphyries.

Slaty structure differs from stratification, and is the result of causes that have affected rocks since their deposition, and even since their consolidation. True slaty structure is only exhibited where the phenomenon of transverse cleavage is present, and this phenomenon of cleavage may be defined as an arrangement of the ultimate particles of an argillaceous or clay rock in planes parallel to one another, without any reference to original bedding, and so that the resulting rock is infinitely divisible in the direction of the cleavage planes.

Besides the ordinary phenomena of bedding and lamination observable in metamorphosed masses, as well as those merely stratified, and manifestly of aqueous origin, there are others regarded as stratified, in which there are no very distinct marks of lamination in each particular mass or seam, but the seams or layers are regularly superimposed. We may thus have igneous and unstratified rocks, such as basalt (a form of lava), and even porphyry, interstratified, although of themselves they have no lamination; and compact masses of limestone, formed perhaps by organized beings, and therefore not arranged in the distinct subordinate beds, are yet strata in the whole group.

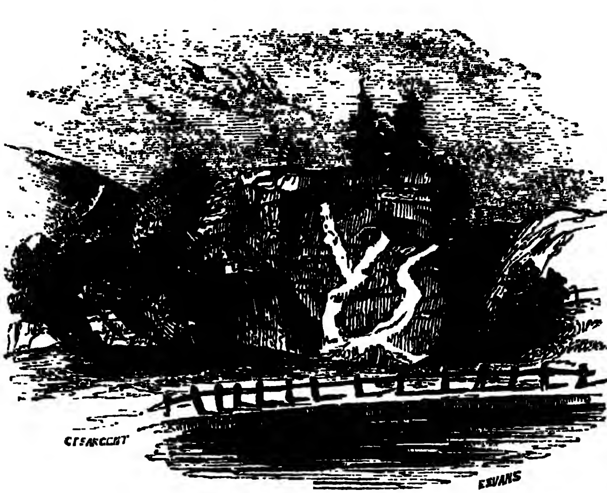
Position of Unstratified Rocks.—Generally speaking, the unstratified rocks are found rising up, and forced through, or else distinctly subordinate in position to those which are stratified. Thus granite, forming sometimes the axis of mountain chains, is also forced up in dome-shaped masses, bringing up the lowest of the aqueous series, or the metamorphic rocks wrapping round its shoulders. Other igneous rocks of great extent are similarly placed. Sometimes, as already mentioned, these rocks alternate in distinct bands with the stratified series, but chiefly with the lowest of them, and wherever we can examine the igneous group, there is always more or less immediately a communication with a more considerable mass of the same kind extending downwards into the depths of the earth. Sometimes, it is true, we find an overspreading mass, like lava, penetrating downwards into cracks and crevices in the stratified rocks, on which it seems to have been poured out in a melting state, but this mass is connected with some crevices of larger dimensions, through which it has been ejected from beneath. By observing carefully the instances of this kind in mountain and other dis-

tricts where such phenomena occur, we come at length to the conclusion that there are two conditions of igneous rock, and that the one which is by far the most widely spread and important, appears to form the fundamental basis on which all stratified rocks ultimately rest, while the other is the accidental result of some local violence, by means of which this matter, in a melted state, has been from time to time agitated, disturbed, and forced out by subterraneous forces, interfering with the regular overlying series, and forming a series of phenomena of secondary importance, because exceptional. Generally, therefore, rocks of mechanical or aqueous origin (in other words, stratified rocks) are superimposed on a basis of igneous rock, which has occasionally disrupted and penetrated them, or which, owing to some deeply seated cause within the earth's crust, has been forced up through them in a melted state, and in that case often seems to overlie them.

It also appears from this, that if, as we suppose, the underlying igneous rock has been exposed to, or constantly preserves a high temperature, the mechanical rocks of aqueous origin in immediate contact may well have undergone some change in consequence, and have assumed for this reason their metamorphic character.

Igneous Rocks.—Let us consider now the nature of those rocks which exhibit marks of igneous origin; and, in the first place, those which appear to form the solid framework of the globe, which are the nuclei of mountain-chains, and below which we know of no rocks whatever.

Granite, Syenite, protogine, &c., porphyry of all kinds, greenstone, serpentine, diallage rock, quartz rock, and others, must be considered as belonging to this group. They are all of chemical, not mechanical formation; they are usually unstratified, and for the most part crystalline; they never contain any trace of organization; they often exhibit jointed structure, being separable readily into cubical or prismatic masses; and they are frequently traversed by rents or fissures (called dykes and mineral veins) of variable dimensions, but exhibiting a great regularity in their general direction, and usually filled either entirely or partially with simple minerals and metallic ores. That many of these rocks have existed at one period in a state of igneous fusion has been generally assumed of late years, owing to the fact that irregular cracks and crevices in the adjacent rocks are filled with similar minerals, either adapted accurately to their shape, or else passing into them like a wedge, altering them at the same time,



GRANITIC VEINS IN GRANITE.

as if by the action of heat. An illustration of this appearance is seen in the annexed cut.

Granite, Syenite, and protogine form, on the whole, the most important, the most widely extended, and the most interesting group of unstratified igneous rocks. They all offer the same general characters, consisting of crystals more or less perfect, of quartz and felspar, mixed either with mica to form true *granite*, with hornblende, as in *Syenite*, or with talc, as in *protogine*. The granite of Egypt offers the best example of the former variety—that of Mont Blanc of the latter; while abundant examples of true granite are common in our own country, as well in Cornwall as in many parts of Scotland.

Generally speaking, of the component parts of granitic rock, felspar is the most abundant, and quartz the next in order. In some varieties, indeed, one of the ingredients is wanting; but these are exceptions.

The magnitude of the constituent parts varies exceedingly, the crystals measuring from several cubic inches to very minute grains. The colour also varies very considerably, being chiefly governed by the felspar, which also determines, on the whole, the condition and appearance of the rock, since, when that is apt to decompose, the whole mass is of comparatively loose texture, and falls asunder on exposure. It is important, therefore, to examine the condition of the exposed pieces of this mineral before selecting granite for any economical purposes.

The structure of granite is often sufficiently remarkable, being more or less distinctly concentric, and on a large scale presenting an appearance greatly resembling stratification, entirely from this cause. It has been conjectured by M. Von Buch that the granite has been sometimes elevated in a viscous state, like a bubble of thick paste, the plastic condition being due to the action of heat. Formed thus into a dome or bell-shaped mountain mass, and left to cool, the surface is assumed to have cracked and split in all directions, leaving a vast multitude of blocks, most of them detached and partially weather-worn by long exposure, but yet retaining so well the general outline, that at a distance the rounded and smooth contour only is recognised, and their innumerable roughnesses lost sight of.

Besides this concentric structure, granite is not unfrequently columnar, and sometimes tabular. These varieties of mechanical condition and structure appear to be the result of a slow though certain rate of cooling which has produced a tendency to crystalline arrangement on a large scale. The decomposition of granite is also often productive of curious and grotesque forms—(see cut).

DISINTEGRATED GRANITE.

Some valuable metalliferous ores are found in granite veins, and they occur still more

commonly where veins traversing other rocks are continued into granite. Oxide of tin and native gold are especially remarkable in relation to this rock.

Granitic rocks not unfrequently form the *aiguilles*, or lofty needle-shaped peaks of high mountain districts. This, at least, is the case in the Old World, where the Alps the Caucasus, the Altai, and the Himalaya mountains all exhibit the same appearance owing to the same cause; but in South America the granite is more commonly seen on the lower heights, probably because of the volcanic origin of a large number of the rocks of that country, and the recent elevation of the great mountain-chains.

The distribution of granitic rocks upon the earth's surface is occasionally unaccompanied by any marks of violence, such as the uplifting and dislocation of strata. In cases of this kind the stratified rocks—if any such have been deposited—have been subsequently removed by denudation. Very extensive tracts of this rock are said to occupy the country between the coast range and the Mountains of the Moon in Africa, and many parts in the south of the same great continent. It forms the centre of the Caucasus, and a considerable portion of the Uralian, Altain, and Himalayan chains in Asia; and in Europe the principal chain of Scandinavia and Finland, the mountain-chains, to the north-east, north, and west of Bohemia, the Carpathians, Alps, and Pyrenees, the Grampians in Scotland, the Mourne Mountains in Ireland, and the Malverns and some other small ridges and domes in England.

Granite and granitic rocks differing only from porphyry in the state of aggregation of the parts, it might naturally be expected that passages should occur from one into the other state. It is indeed probable that many of the changes of appearance which are thus denoted by distinct names, because the condition of the minerals is different, owe their modifications of form merely to some variations in the rate of cooling down from igneous fusion, and this indeed is evident from the fact that, in the course of the same vein, and in different parts of the same injected mass, we have these varieties exemplified.

Porphyritic rocks, however, form a group, or rather a number of groups, in which the presence of imbedded crystals in a base is a very constant characteristic. In these cases the crystals are usually quartz and felspar, and the base sometimes claystone, sometimes hornstone, and sometimes compact felspar. Porphyry is sometimes stratified, alternating with distinct strata of mechanical rocks; but it is much more commonly massive, and in that state is often traversed by rich mineral veins. The most valuable mines of Mexico occur in Syenitic porphyry; the mines of Hungary, also of great value, are situated in the same kind of rock, and many other celebrated mining localities are similarly placed. Porphyry is very widely distributed, although not so widely as granite. It abounds chiefly in some districts in Upper Egypt, in Sweden, in Siberia, and in North and South America. Some of the porphyritic rocks contain cavities often partially or entirely filled with simple minerals. These are called amygdaloidal rocks, from the almond shape of the vesicular cavities.

Greenstone is often porphyritic, consisting in that case of hornblende united with felspar. Common greenstone is a granular aggregate of hornblende and felspar, and may be called porphyritic when large crystals of felspar are also present and disseminated. When the crystals form part of the granular base, the mixture becomes *greenstone porphyry*, the black porphyry of the ancients. *Green porphyry* is a name given to the compound when the granular basis is not visible to the naked eye, and the rock is uniform and simple, of a blackish green colour, and including crystals of compact felspar.

These rocks occur abundantly in Scotland occasionally bedded with clay slate and

mica slate. They also abound in Norway, Saxony, Bohemia, Silesia, Thuringia, Hungary, and the Swiss and Savoy Alps. In the Isle of Skye and elsewhere the greenstone contains hypersthene, and is thus called *Hypersthene greenstone.*

Serpentine or Ophiolite is an ornamental stone, sometimes described as a simple mineral, but more properly considered amongst rock formations. It is of a green colour, soft, rather greasy to the touch, and frequently contains imbedded minerals, chiefly magnesian and siliceous. Besides the iron that enters into its composition as a mineral, this rock generally contains some ores of the same metal, such as magnetic iron ore, chromate of iron, &c., and on exposure and the consequent oxidation, the surface of the rock is apt to decompose into a yellowish earth; but as it resists the weather far more than the gneiss and other rocks with which it is usually associated, peaks and little domes of it are not unfrequently seen rising above the surface in districts where it abounds.

Like other magnesian rocks, serpentine is very inimical to vegetation, and may be known by the bare, bleak, naked appearance and sombre colour of its surface. It is abundant in the Alps, in beds of enormous thickness. It is also found in Cornwall, in Scotland, in most of the mountain districts of Europe and North America, and in Mexico.

A mixture of serpentine with limestone forms the rare and beautiful verde-antico of the ancients.

Diallage Rock is nearly allied to serpentine, and is composed principally of felspar and diallage. It is frequently traversed by veins of diallage and of various magnesian minerals. It is abundant in serpentine districts.

Trachytic Rocks.—We have hitherto been considering the various rocks of igneous origin, without reference to their position in any order of arrangement that may be adopted, and have confined ourselves to those which exhibit felspathic and hornblendic characteristics. Felspar, indeed, abounds in almost all rocks of this kind, in the oldest granites as well as the most modern lavas; but in the latter case, and in what may be called volcanic rocks generally, as distinguished from the group of underlying igneous rocks, the form assumed by felspar connects it with the rock called *trachyte*, under which name is included a very important group, distinct from the basalts, and occupying about the same position in modern rocks that granites and porphyries do in those of more ancient date.

Simple trachyte is a true felspathic rock, generally of a gray colour, very coarse, rough and sharp to the touch, and apt to disintegrate on exposure to the weather. It is sometimes used as a building stone, but is not good for this purpose; an instance of which may be seen in the stone originally used for Cologne Cathedral, obtained from behind the Drachenfels on the Rhine, which is already so much decomposed that much of it has been removed during the recent restorations of the cathedral. Trachyte is generally porphyritic, containing crystals of felspar, hornblende, augite mica, iron glance, and occasionally quartz. Pitchstone and pumice are varieties of trachyte; and trachytic porphyry, in which numerous crystals are imbedded in a trachytic base, is also not uncommon. Besides the ordinary and more compact forms of trachyte, the same mineral is very often found in pulverulent masses forming *tuff* or *tufa*, in the manufacture of hydraulic cement.

Trachytic rocks, when they contain a large admixture of hornblende and augite, but in which these minerals do not actually preponderate, have been called *greystone*, and those in the volcanic series seem to correspond to the Syenites and greenstones of the underlying series. Hornblende and augite, which exhibit themselves under an almost

infinite variety of form and circumstance, and which have been determined to be but different forms assumed by the same mineral, owing to differences of the rate of cooling, are the most important ingredients of these rocks, and present a ready means for establishing a classification of them. They appear to be formed under certain circumstances during the cooling of igneous rocks, and offer near approximations to some artificial products, the result of artificial heat.

Basaltic Rocks.—Besides the rocks distinctly and properly trachytic, and the greystones or hornblendic and augitic trachytes, there is a third, a very large and important class, in which hornblende, augite, hypersthene, diallage, and a group of minerals having many important characters in common, either predominate very greatly over the felspar, or absolutely exclude it. These form the group of basalts and basaltic rocks, rocks familiarly spoken of by all geologists, occurring in every geological formation, and formed even at the present day, but presenting themselves under various aspects, and appearing in erupted beds, in huge columnar masses, and in veins and dykes of all degrees of magnitude.

Basalt is a rock of great importance in reference to geology, and its presence may generally be considered to point to the former existence of active volcanoes, and the eruption of rock in a state of igneous fusion. Basalt is lava erupted at a time anterior to the existing epoch, and often probably under water, and therefore often, no doubt, exposed to conditions different from those which affect modern lava poured out on the earth's surface.

Many of the basaltic rocks having been found to exist in steps, forming a succession of terraces, resulting from the way in which they were thrown out upon the surface or beneath the sea, have received the name of *trap rocks*, from the Swedish word *trappa*, a stair or step, and are now commonly so designated by geologists. Under the general name of trap rock is included the whole tribe of basalts, and indeed all those rocks of volcanic origin erupted like lava, and in any sense intrusive.

Basaltic rocks are not less widely distributed than granitic rocks and porphyries, and like these they occur in two forms, either spread out upon the surface, or filling up cracks and fissures in the stratified and other rocks which they penetrate. They are generally of an iron gray colour, approaching to black, and often contain various imbedded minerals, sometimes in cavities and sometimes disseminated. Crystals of olivine are especially common in certain kinds of basalts, and replace the felspar of the older rocks. The texture of basalt is often tough and hard; it has a good conchoidal fracture, and often a sort of semi-crystalline structure, and is very liable to superficial decomposition, becoming then of a rusty brown colour, and forming an admirable vegetable soil. In structure it is very frequently columnar, owing, it would seem, rather to a tendency to form spherical concretions in cooling than to any more complete crystalline arrangement into prisms. Some very remarkable examples of this structure characterize the basalt of Giant's Causeway, of the Isle of Staffa, and other spots in the north of Ireland and the western islands of Scotland; and similar appearances may be observed in basaltic rocks on the Rhine, near the Siebengebirge, and in central France. The grotto of cheeses, in the Eifel (see cut), affords a good example of this structure.

Besides these localities, there are several others, not only in Europe, but elsewhere in various parts of the world, in which may be traced the marks of volcanoes either actually now vomiting forth fire and lava, or at present extinct, but leaving abundant evidence of their former existence.

Basaltic rocks are not confined to the surface or to geological epochs actually or comparatively recent, but are met with also in the older rocks, sometimes regularly bedded, and sometimes forming mountain masses. Perhaps the largest and most widely spread of all these is that remarkable table land occupying an important part of central India, but a very extensive district in South Africa is also capped in the same manner. It is not unlikely that in most cases in which the basalt is widely spread it has been poured out beneath the sea.

CHEESE GROTTO IN THE EIFEL.

It appears, then, on the whole, that whatever may be the case with regard to rocks manifestly of aqueous origin, which we have not yet taken into the account, there is good evidence of the existence of another very distinct series, which may possibly be of great age even in its present form, but concerning which, as the masses of which it is made up owe their mode of aggregation to chemical and not mechanical agency, no definite age can be ascertained from their appearance and mineral condition only.

It also appears, that in addition to an interesting and very remarkable series of such rocks, known by the names of granite, porphyry, greenstone, and others, not at all resembling recent volcanic products, but yet crystalline, and manifestly of igneous origin, there is another class, those called trap rocks and basalt, which appear to be of volcanic origin, and which, instead of originally forming part of the solid framework of the earth, have burst through this framework and the beds resting upon it, and coming up in a molten condition, have spread themselves out upon the surface. These, therefore, even if occasionally bedded, are yet, in strict sense, intrusive. These two great classes of igneous rocks, while they exhibit many points in common, are yet very distinct, and they offer much important matter for consideration, if we desire to investigate the cause of the difference that exists between rocks whose mineral ingredients and state of aggregation are so similar.

Metamorphic Rocks.—It is one of the proofs of the true igneous origin of these rocks, that when they have come in contact with others manifestly of aqueous and mechanical origin, they have altered them as by the action of intense heat. It is therefore not surprising that there should be whole classes of rocks immediately adjacent to the great underlying masses of granite, porphyry, &c., partaking of this character of change, and affected by the vicinity of so much heated matter.

Neither can we be astonished when we find that these rocks so affected often exhibit very striking resemblances to the igneous rocks they approach, for there can be no reasonable doubt that they were derived immediately and directly from them, and were nothing more originally than broken fragments re-arranged into beds or layers by the action of water. Thus there is no violent transition when we pass from the examination of granite, where quartz, felspar, and mica are chemically arranged, to gneiss, where the same minerals are arranged mechanically; and we need not wonder if, during the

deposit of these water-worn fragments, the particles of felspar should have been sometimes carried on, leaving the heavier ones of quartz and mica behind to become *mica schist*, and form a separate and distinct deposit; or that the minute pounded fragments carried to the greatest distance should have been ultimately thrown down as fine mud, which afterwards, in the course of time, became *clay slate*. In this way we can account for the existence of the three great classes of stratified metamorphic rocks, which, while they are evidently mechanical, are no less evidently changed from their original condition, some more and some less, but which, though thus changed, bear marks of their original condition no less than of their subsequent modifications.

The rocks called metamorphic are of two kinds, stratified and unstratified. The latter include quartz rock, and perfectly crystalline limestones or marble; the former are generally considered as forming three groups, designated by the terms gneiss, mica slate, and clay slate. Other rocks of the same character, and differing in appearance, may deserve a few words of separate description; but these, in point of fact, are the varieties with which it is chiefly requisite to be acquainted.

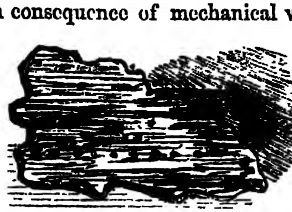
Gneiss, as has been already said, is a rock, of which the materials are quartz, felspar, and mica—the same, therefore, as those of which granite is compounded; but these materials are arranged in distinct layers, as we might imagine would be the case if the granite were ground down to fragments, and then re-composed into a stratified rock, after being conveyed for a greater or less distance by water.

GNEISS AND GRANITE.

But gneiss is not merely a re-constructed granite. It has been since changed and consolidated into a compact rock. It has been sometimes split and fissured in various directions, and these fissures have often been filled with granite veins, while occasionally the gneiss is not at all less crystalline than true granite itself, but passes by insensible gradations into the latter, losing, as it approaches this state, all appearance of stratification, so slowly that it is very difficult to mark accurately the point of absolute transition.

As however gneiss passes downwards in this way into granite, so does it pass upwards by a schistose and less perfectly consolidated state into *mica slate*.

Gneiss and all the other metamorphic rocks have frequently undergone great changes in consequence of mechanical violence, and the most singular contortions have sometimes been produced in rocks of this kind, apparently by violent squeezing. In some parts of the western islands of Scotland very remarkable instances of this may be seen, and have been well described by Dr. M'Culloch.



MICA SCHIST.

Gneiss is often found wrapping round the central granitic axis of mountain chains. In these cases it has manifestly undergone elevation with the granite, and has been greatly acted on during this process.

Mica slate or schist, which, next to gneiss, is among the most abundant of the meta-

morphic rocks, consists apparently of decomposed granite, from which the felspar has been removed. It is more slaty than gneiss, mica being the predominant mineral, and the quartz is often arranged in thin lenticular masses interposed between the mica, or is formed into thicker beds, with a more or less abundant distribution of mica. When the mica is altogether absent, there is nothing left but quartz rock. Mica schist passes, as already observed, from gneiss, in some cases the gneiss having been, as it were, an intervening step in the process of deposition. It occasionally happens that although the mica is absent, it is replaced either by talc or by chlorite. Mica schist is far less abundant than gneiss in Scotland, but abounds in the north-west and west of Ireland, where much of the peculiar character of the scenery is derived from the presence of this rock. It is not unusual to find minerals of various kinds distributed in mica slate, amongst which may be mentioned garnets, tourmaline, schorl, chiastolite, and cyanite, as well as emerald, besides some ores of metals. Many instances are also known of beds of granular limestone and dolomite, of quartz rock, and of iron ore, being also present in rocks of this kind.

Mica schist is always distinctly bedded, but the strata are frequently much contorted. Although it is most usual to find this rock intermediate between gneiss and clay slate, this is by no means always the case, and it is very widely distributed throughout the earth without reference to the other great classes of metamorphic rocks.

GNEISS AND MICA SCHIST

Clay slate is not less distinctive and not less perfectly characterized as a metamorphic rock than any of those we have hitherto considered. It is, however, decidedly fossiliferous in many cases, and thus occupies a double place, requiring to be alluded to in its metamorphic character now, and afterwards appearing among the rocks regularly stratified and of various geological epochs.

The common appearance and general character of clay slate are well seen in the finer and more perfect specimens, selected on account of their fine grain and perfect cleavage, and used for roofing houses and various economical purposes. Slate varies, however, from this condition to a much coarser variety, containing few evident marks of slaty structure, and being far more siliceous and gritty. It resembles indurated clay or shale, and consists of nearly fifty per cent. of silica with about twenty-five of alumina, mixed with a variable quantity of oxide of iron, magnesia, potash, and carbon. In the state in which it generally occurs, the particles have undergone change and re-arrangement of position since the whole mass was deposited, and there is good evidence to prove that large masses have been disturbed, and even compressed and contorted by the intrusion of other rocks, being often elevated into mountain masses flanking the igneous rocks, whilst the beds are frequently inclined at high angles, as may be seen in many districts of North Wales, Cumberland and Westmoreland, Devon, Cornwall, Ireland, Scotland, and many other parts of the world.

This re-arrangement of the particles after consolidation and even after subsequent disturbance is a very remarkable fact, and one which renders it necessary to call in the aid of the metamorphism as the only means of explanation.

In North Wales it is no unusual thing to see slates in which the original lines of

bedding are perfectly manifest by the fossils observed at the partings. These lines are now contorted and twisted in the strangest, most complicated, and most grotesque manner, and a diagram can scarcely do justice to the extent of this complication. But the same beds of clay, which, after being first quietly deposited as mud at the bottom of the sea, have afterwards become consolidated, and then by violent squeezing and elevatory force have been removed from their original position, and made to exhibit the appearances above described, are yet smooth, regular, and uniform, for they will split readily into infinitely thin laminæ parallel to one another; they will also separate into cubical masses of certain definite size, and they will present this structure in precisely the same way, and over a great extent of country, without the slightest reference to what may be called the accidents of the bed, and apparently obeying only some law concerning which we know very little, but according to whose action the internal particles of bodies in a solid state change their position relatively to one another, and so far alter the character of the rocks as to justify the application of the term metamorphic.

The phenomena just described are called *structural*, as affecting the intimate structure of the mass, and not merely its external form. The effects produced are reducible to two, cleavage and jointed structure—this latter being, in fact, imperfect crystalline structure.

The condition of cleavage is always worthy of notice when occurring in rock masses; but where there is no other indication of crystalline structure, and the mineral is one which, like clay or aluminous earth mixed with silica, has no regular crystalline form, this condition is the more singular. It is not less remarkable to find that rock masses are affected by this peculiarity in a uniform manner over wide spaces; that the action has gone on regardless of any change in the nature of the mineral; and even if for a space intermitted, in consequence of the presence of some rock which cannot exhibit this appearance, such as the purer sandstones and quartz rock, it yet takes on again at a little distance, preserving the same direction and strictly parallel to itself.

True slaty cleavage is generally transverse to the bedding, and often in the direction of the strike. It partially but not entirely obliterates true bedding, but it does so by no very marked interference; and if fossils are present, although they are cut across and intersected by the cleavage planes, the indications of organic existence still remain, and give the best of all evidence with regard to the direction and position of the beds.

Jointed structure is quite distinct from cleavage, its tendency being to induce the separation of a rock into cubical masses, by cracks parallel to one another at certain distances and in the same direction. In most mountain masses, whether crystalline or not, in granite, in limestone, even in sandstone and coal, there may be found—and this is well known to quarrymen—certain facilities for working in one direction rather than another. Various technical expressions are used to denote this, but no fact is more universal; and the direction, when taken by the compass, is often found to have a well-marked relation to magnetic north and south. Of course, in order to produce cubical or columnar structure, there must be two sets of joints, making considerable angles one with another, but such is the case in almost all rocks.

There are still two kinds of metamorphic rock not hitherto alluded to—namely, metamorphic limestone or crystalline marble, and metamorphic sandstone or quartz rock. Both these substances are occasionally met with in veins in other metamorphic rocks, and both must be distinguished from the products of segregation; particles of

the same kind, when combined with other mineral substances, under certain conditions, having a tendency to separate and group themselves together in veins or cavities.

Crystalline metamorphic limestones are always granular in their structure, and the peculiar appearance thus characterized will be understood by comparing a piece of marble with a fragment of limestone. All the fine kinds of marble are of this kind, and are generally found in the vicinity of igneous rock.

Quartz rock, or metamorphic sandstone, is also granular, and is distinguished without difficulty as well by its appearance as by its geological position from any rocks for which it might be mistaken.

Distribution of Metamorphic Rocks.—Having said so much with regard to the general appearance and nature of metamorphic rocks as minerals, we have now to allude to their distribution, and to the geological phenomena connected with their presence.

As a group, they are very widely distributed, very closely related both to the underlying igneous and the overlying aqueous rocks, singularly alike in many respects over very extensive districts, and at vast intervals; and often covered up superficially, by a great thickness of other rocks, apparently partaking of the character of universal formations. From all this it might be imagined that they were contemporaneous, or nearly so—that they form a vast mantle, spreading far and wide, and of much greater antiquity than any of those stratified fossiliferous rocks which in most countries are found upon the surface, in the plains, and in the valleys. But such a conclusion would be premature and very unphilosophical. Whenever, indeed, we find fossiliferous stratified rocks resting upon metamorphic rocks, and these again reposing on granite, the *relative* age is clearly exhibited, but only the relative age, and the metamorphic and igneous rocks may manifestly have been brought into their present condition at any period between the first creation of the earth and the deposit of the lowest unaltered rock. As an example of this, we may take an instance occurring in the Alps, where a true clay slate rests upon granitic rock, but there is distinct evidence from fossils that the slate is a very recent rock, geologically speaking. The slates of Wales, on the other hand, which hardly differ geologically, are among the oldest strata of which we have any knowledge, and most unquestionably were brought into their slaty condition millions of ages before the others were deposited as mud.

The igneous and metamorphic strata of one district, therefore, may be of very different ages from those of another, however closely there may be a resemblance of mineral structure. Chemical action may have been going on at great depths beneath the surface continuously during the whole of the earth's history, and may be still going on; so that the undulatory movements of the earth's superficial crust may have been the means of bringing successively under the influence of heat those substances deposited from suspension in water, and may perhaps alter them, first rendering them metamorphic, and afterwards converting them into igneous rocks.

Aqueous Rocks.—Having now considered the nature of those rocks which form the actual skeleton and framework of the earth, and below which we cannot expect to find any indications of mechanical origin, and having also discussed the nature of that class immediately resting upon these, and often greatly altered by their contact, we pass on to describe that vast group of stratified fossiliferous rocks which form the great object of investigation in Geology, by which alone we obtain a distinct knowledge of succession and of the earth's history, and which, in the information of this

kind which they communicate, are equally remarkable for their vast variety, their great thickness, and their abundant and characteristic organic remains.

The first inquiry made by an observer anxious to obtain and render available a knowledge of this subject, will almost necessarily be—what are the subdivisions and the characteristics of the different groups of these rocks?—what principle of classification is followed, and how far is this principle a natural one, or merely founded upon accidental or unimportant characters? As a general answer to all such inquiries, it is as well to say at once that the principle of classification in Geology is natural; that it is founded upon exceedingly important and very striking characters; that it is strictly real, but that it often presents great difficulties when applied in detail; that it requires all the accurate and minute knowledge of the experienced naturalist to avoid errors in its application. In order to explain the nature and value of this method, it will be necessary first to consider what kinds of arrangement are possible, and the relative value of each.

It is true that since the various aqueous deposits exhibit some differences of mineral composition, and some peculiarities in their state of aggregation when examined in particular districts, the mere determination of the fact that sandstones, limestones, and clays were grouped in a certain manner, would be something gained. But this, after all, advances us but a small step; and when we examine rocks in their places, it will soon be found that such distinctions, however clearly established in one district, do not help us at all in another at no great distance. Mere mineral characters of this kind are therefore practically of little value, and although in the earlier days of Geology the student was led to suppose that certain strata, such as red marl, grauwacke, and others were universal, and that limestones or sandstones might be determined at once to belong to a certain age by their appearance and crystallization, no one now would venture, without good local knowledge and familiar acquaintance with the subject by other and more accurate means, even to suggest the position of a rock by its mere mineral and lithological character.

But if mere mineral character of itself has little value, it may still be imagined that, combined with local knowledge, and assisted by a knowledge of the general superposition of strata, it might enable us to group together certain strata. No doubt this is partially the case; and there are some rocks which, when once determined by other means, are very easily recognised. But to identify a rock found in a new country is never safe, if we are guided only by its resemblance to a similar rock in a district we are already acquainted with. The resemblance may suggest a place for the specimen, but it cannot enable us to assert positively that such is its place.

In any given spot the order of superposition is a matter of great importance to determine, and the nature of the alternations of limestone, sandstones, and clays of various kinds, will often exhibit a certain definite system, which it is of no little value to know. But this is not sufficient to enable us to arrive at any distinct and useful geological conclusions; for if we examine and make out with perfect distinctness, according to this method, the exact order of superposition in one district, we are not necessarily led to a true identification with another district, unless we can actually connect the two by sections.

Fossils.—There is, however, another characteristic of the rocks we are now considering, and it is one which relates to their contents rather than immediately to themselves; but which, insufficient as it would seem for classification to those who first examined these contents, is, in point of fact, when combined with the others, perfectly

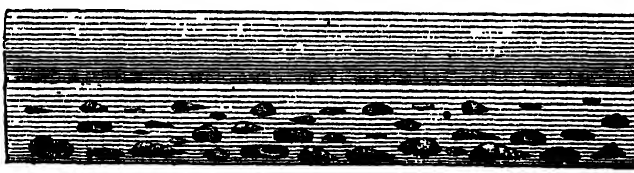
sufficient and satisfactory, and almost universally applicable. These aqueous rocks are, for the most part, fossiliferous—that is, they contain the remains of the animals and vegetables existing at the time of their deposit, preserved in a state which enables us to examine and recognise them, and in sufficient abundance and variety to become in a proper sense characteristic.

It becomes important to consider the exact meaning of this appearance. How is it, we may ask, that animals or vegetables can have left bones, shells, or the leaves or trunks of trees entombed and preserved in sand, mud, or limestone? Are such things going on now? and how can we best explain the various circumstances of the case?

Both in the case of minerals, therefore, and in that of the animals or vegetables found in strata, we are forced to consider the general subject of Natural History before we can fully see the nature and understand the arguments of Geology.

One of the first inquiries with regard to these organic remains is concerning the state in which they exist, and their relative and actual abundance. With regard to both these points there is much that is highly interesting.

Under the name of *fossils*, which were once and are sometimes still called *petrifactions*, the remains in question have long attracted attention. Varying according to the locality in which they occur, in one place we find only such minute and fragmentary remains that we must call in the aid of the microscope before we can arrive at any satisfactory conclusion. Another rock will be found actually made up of the exceedingly small shells or secreted stony skeletons of some marine animal, such as a species of coral. A third will abound with broken shells, while another will contain them



SHELLS BURIED IN MUD UNDER WATER.

more sparingly, but also more perfectly. Here a limestone rock will exhibit the most delicate and perfect impression of some insect, crustacean or fish; there a sandstone presents only the most rough and imperfect fragments of bone barely capable of showing structure. In caverns in England we find embedded the bones and teeth of hyænas, bears, and elephants; in South America the mud contains complete skeletons of monstrous sloths and armadillos; while in the Polar Seas the frozen gravel is found to yield, from time to time, the complete and uninjured carcasses of gigantic elephants and rhinoceroses, animals of which no living individual has approached within hundreds and even thousands of miles of the spot within the memory of man.

These so-called fossils, too, exist in all possible mineral conditions.

We find sometimes the bones and teeth of large animals, and the shells and other hard parts of smaller ones, distributed amongst the materials accumulated together in heaps by the action of water, and very little if at all changed from their original condition.

These hard parts have sometimes had a portion of their substance removed, so that they have become more fragile; at other times, their natural cavities and interstices are filled up by stony infiltrations, hardening and solidifying them; while occasionally interstices left, after the decay of a portion, are filled up in the same way with stony infiltrations.

Sometimes it happens that not only the interstices are filled up, but the whole of the rest of the substance is changed, particle for particle, into some new mineral, in which all the details of organic structure are preserved, while occasionally it is found that the place once occupied by the organic body has been filled up by some mineral substance not exhibiting structure.

Lastly, it happens occasionally that even the soft parts have been retained, as in the ammonites, &c., of the Oxford clay; the skin of ichthyosaurus in the lias; while in particular cases the merest indications, such as the footmarks of an animal upon sand, are all we have left to astonish and instruct us. In the annexed engraving there is seen the mark of a bird's foot, and imprints of drops of rain.

IMPRINT OF THE FOOT OF A BIRD, AND MARKS OF RAIN-DROPS ON A SLAB OF SANDSTONE.

All these are the different forms in which bodies, originally secreted by living animals, have been preserved, and they occur in some one or other of such forms in almost every bed of the whole number we discover. They are incredibly abundant, but they are distributed in groups.

Distribution of organic Beings on the Earth.—The nature of the groups, and the consideration of what kind of animals would be buried in the sea in particular spots at present, is the next subject of consideration. This involves some acquaintance with the geographical limits and distribution of animals and vegetables both on the land and in the sea.

If we are to consider what are likely to be the causes of the prevalence of a species or a group of species in any spot, we must make ourselves familiar with the facts on record with regard to this subject.

Now it is well known that certain animals and vegetables, extremely common in this country, do not naturally range beyond particular limits, while the animals and plants of distant regions are only to be found here when introduced by the agency of man. In many of these cases there is no apparent difficulty in acclimatizing the newly-introduced race, and in some the new position they are made to occupy appears even more favourable for their development than that to which they were born. We can only say that certain tribes are indigenous to certain latitudes, and more or less limited in their range beyond those natural bounds. Such matters will probably be more fully discussed and explained elsewhere in speaking of the distribution of animals and vegetables in space, which is an important part of Zoology and Botany; but we may here briefly advert to some simple but effectual illustrations that will enable the reader to understand subsequent reasonings.

One of the main facts deduced from natural-history considerations of the distribu-

tion of animals and vegetables is the very important one that, in different parts of the world, under similar conditions of existence, we do not find the same species indigenous, but a great variety of species often manifestly framed to perform similar functions and operations, and greatly resembling each other in essential characters, but which not being identical may properly be called *analogous* or *representative*.

There is hardly a more important law of organic life than that according to which the same effects are produced in nature—the same kinds of country occupied—the same temperature and altitude tenanted, by groups which thus show adaptation by the method of representation and not of identity.

Take, for instance, the forests of Brazil, and let the animals there indigenous be compared with others met with in similar districts of tropical Asia. Each has its carnivorous animals, its monkeys, its bats, its gnawing animals, its ruminating animals, its pig-like animals (tapirs and horses), and even its marsupials and edentates—and yet there is absolutely not one identical species in the two continents. And if we look at the isolated land of Australia, the islands off the east coast of Asia, or those small islands —mere specks in the ocean—the Galapagos, off the western shore of South America, each of these has its own peculiar fauna, and almost its own flora. Each exhibits relations to the fauna of the nearest land, but it is by representation, not identity. In the consideration of this subject there is, however, one apparent difficulty, since the islands in the vicinity of continents sometimes have the same species of animals and vegetables as those of the adjacent main-land, while in other cases—as in the Galapagos —these are only similar and not identical. It has been left to the geologist to explain the reason of this singular fact.

The law of representative species as hitherto considered has reference to space generally, and extends in two directions—horizontally and vertically. It refers also not only to land animals, but to those which inhabit the water. In other words, as in ascending high mountains we pass through various temperatures, and even within the tropics may rise to the level at which there is constantly snow on the ground, thus realizing the polar conditions, so in the distribution of animals those found on the higher ground exhibit analogies with polar species. In the sea, where it appears that the temperature at great depths, even in some tropical latitudes, is that of water at its greatest density, about 40°, and where, owing to other circumstances, the conditions favourable for the abundant development of life exist only near the surface, the great depths, if tenanted at all, are tenanted by species resembling those which in colder seas are found nearer the surface. Thus we have marine zones of similar organic condition, just as on land we have zones dividing different botanical and zoological regions.

Distribution in Time.—Now in Geology this same law of representation is found to have been carried out in past time, or in other words, the species characteristic of any geological formation are representative in time as well as space of the species now existing. The whole mystery of extinct species is revealed by the due consideration of this law, and a fact perhaps the most startling of any of those taught by geological investigation, is thus seen to be only another form of a condition of things universal upon the earth at present.

For what can be more striking than to be told that in ancient times there existed on this earth of ours races of beings now passed away, and to be taught the peculiarities of size, form, and even habit of animals and vegetables which no eye of man has ever seen in a living state; what more marvellous than this reconstruction of long lost organic forms—this clothing with flesh and blood the dry and scattered bones of

skeletons—has ever been thought of by the imagination of man, even in its wildest flights?

And yet all this is now effected, and in the most satisfactory manner, by those naturalists who have been contented to study with patience and perseverance the works and ways of existing nature. When we find that she adopts methods and obeys laws which are unchangeable, we in fact only add one more to the innumerable proofs of order and system which pervade all the works of creation. The extension of a law is not the adoption of a new law; and so far as we are aware, no new method has been required or adopted.

But we must refer again to the important and interesting subject of ancient organic nature, and learn the extent to which naturalists have advanced in proving the fact

GREAT IRISH ELK.

of the ancient existence of animals and vegetables now no longer met with, as well as the limits of discovery, and the reasons for arriving at the conclusion attained.

And here the main argument employed is still that of analogy, and the main proofs rest on the accordance of the past with the present.

To take the cases nearest our own times, who is not aware of the fact that the bones of the beaver, the wolf, and of many animals now living in other parts of Europe are constantly met with, and that these creatures must, not long ago, have inhabited the British islands? The progress of civilization may, it is said, have produced this partial and local extinction. Let it be so; but what is the case with regard to other animals, such as the great Irish elk? This animal, of which the perfect skeleton has often been found in the bogs of Ireland, cannot have lived in the country where we find it without having been observed, and yet we have no record of its existence as a living animal. It is quite gone—the last of its race has died, and left only a few fragments for us to put together in order to show how great the changes have been even since the surface of Ireland and the Isle of Man could afford food and shelter for these giant animals. Smaller deer are still in the British islands; the rein-deer and the elk still tread the frozen plains of Lapland and the forests of North America; but this most gigantic of the deer tribe is gone, although not without leaving sure marks of its former prevalence.

Without dwelling any further at present on these examples, let us consider another also of great interest, in which we have not merely the dry skeleton, but the very flesh and skin of an ancient inhabitant of northern Europe.

In the wild desert plains of Siberia, close to the arctic circle, many miles north of the last traces of arborescent vegetation, and where perpetual frost binds together into a rock those gravelly heaps which in England and northern Europe are loose and shingly, there are found, from time to time, the bones of animals which once inhabited that district. And what are these animals? Are they the progenitors of the wolves, the dogs, the foxes, the bears, which are now the only creatures, except man, who disturb such solitudes? Do we find occasionally a straggler from the still more glacial climates in the vicinity? By no means. These frozen gravel cliffs of the icy sea are partly made up of the bones of elephants, of rhinoceroses, of hippopotamuses, and of such like animals, in incredible abundance.

For very many years whole cargoes of ivory have been brought annually from these store-houses, and most of the ivory used in the beautiful German carvings of the middle ages was derived hence. Here, then, it would seem probable these animals must have lived, for their bones are not broken or injured by rolling, and have certainly not been carried far. But this is not all, nor is it, perhaps, the most extraordinary fact with regard to this subject, for it is not many years since the entire carcass of an elephant was obtained from these cliffs, the flesh having been preserved in a sufficiently undecomposed state to serve as food for wild animals, and a part of the skin, hair, and wool—for this creature was warmly clad—in such a state of preservation that they were transported with the skeleton to the museum of St. Petersburg. Since then many such carcasses have been discovered, and for a few hundred pounds it is said that we might now bring to England an elephant thus preserved—one of the ancient inhabitants of Northern Europe.

Now, when we look at the carcass of the animal thus handed down in a perfect state, we find that it does not exactly agree with any of those at present living on the globe. The differences, indeed, are not considerable, and are evidently such as would fit the animal better for the conditions of its abode and climate as well as food. There is adaptation in every part of every skeleton, and the principle of adaptation of parts is that on which the comparative anatomist and naturalist must work to obtain any general results in this science.

Each part of every animal is admirably fitted to work with every other part in producing the adaptation of the whole to the peculiar necessity of the creature. This is a fact well proved by a thousand examples daily before us, and it is universally and minutely true.

Since, then, we find that there are certain animals different from the present inhabitants, but whose remains are found under circumstances which render it clear that they formerly inhabited a given district; and that these animals are at present unknown upon the earth, the first step is gained towards a knowledge of the history of extinct species. But there is another point to be considered—the representation of the present races. This I might illustrate by reference to the Irish elk, or the elephants of Siberia, but I prefer taking a more striking example.

In New Zealand there exists at present, although it is now rare, a small, wingless bird—not like an ostrich, but absolutely wingless, and covered with hair. This animal is called the apteryx, and was the largest animal found in New Zealand at the time of its discovery. In the island of Mauritius there appears to have formerly existed a curious wingless animal about the size of a turkey, called the dodo; and the beak and feet of this animal, as well as a drawing of it, are preserved in the British Museum. No living dodo has, however, been seen in modern times.

In the island of New Zealand there are also found, in the gravel, some fossil bones nearly as large as the thigh bone of an ox; and on careful examination of the bones found in this gravel, a number of species of wingless birds have been formed, which exhibit, in regular gradation, a series of animals of various sizes, more or less like the apteryx, all wingless, but the largest of them much more gigantic than any ostrich. There is here, then, a distinct representation in time.

Use of Fossils in Geology.—We have next to consider what is the use of these fossil remains to the geologist.

It will have been seen that in the crust of the earth there are a number of layers, or beds, one over another, and if these contain the remains of animals or vegetables in any abundance—if the remains are so placed that they involve of necessity the gradual formation of these beds during successive generations of animals—there result two great conclusions bearing on geological investigation: first, that each bed must have been formed separately by itself, and before any of the others were placed upon it; and the more there appears to be any distinct group of fossils or mineral character peculiar to a bed, the more is this truth made manifest. But it is also seen, in the second place, that beds thus formed must have required a long period of time for their elaboration, and that, if this is the case, even with regard to one bed of moderate thickness, it is still more so, when we consider the vast number and great thickness of the beds presented to our notice.

The use of fossils, in geological investigations, is thus very considerable. They tell us of time elapsed, as well as mechanical changes effected, and of conditions of existence of animals and vegetables different from the present. They are also, by their specific character, by their mode of grouping, and by the succession observable with regard to them, characteristic of geological formations. They are, in fact, the very hieroglyphics of nature, marking the condition of the earth at the time and place of their deposit; and thus they are the true materials from which we deduce the earth's history.

But fossils are much more than mere indications of the history of the time to which they refer. They themselves express the very language of nature; they bear actual, direct, and unquestionable testimony to the course of nature; and, when properly con-

sidered, they exhibit distinct proof of a long series of successive creations, characterizing different epochs in the earth's progress. Viewed in this light they become the groundwork of correct geological classification, and every successive advance in our knowledge of them proves how safely and truly they may act as our guide in this respect.

Such is their value in geology; but the bearing of this subject of extinct species on natural history generally, as it refers to living forms, is no less real and no less important. Fossils afford numerous links in the great chain of organized beings; they explain difficulties otherwise inexplicable; they suggest reasons and causes for the most unusual variations from the ordinary course of nature; and they teach us the important truth, that throughout all time there has been a perfectly uniform plan pursued in the construction of the world, and its adaptation for successive races of beings, but that this plan has admitted of innumerable modifications in the mode of carrying it out,—all evidently and admirably adapted to changing circumstances.

But the one principle involved in the whole subject of fossils—the means by which we determine their nature, and discover the value of the evidence they yield—is still derived from the study of existing nature.

No new principle is introduced—no new or different method discovered; nature is still, in all essential points, the same, and has been the same throughout all time. All that we can know with certainty, with regard to the past, is derived from the study of the present, and we are confident of the truth of the history these fossils teach us, because, and only because, that history does not involve any considerations that disturb the harmony and the uniformity of action of the great laws of organic existence. It is impossible too earnestly or too forcibly to impress on the reader the importance of this view of the case, for it is only by comprehending the nature of the argument, and perceiving its firm and sound basis, that the true value of geological conclusions is understood, and the standard obtained by which to measure them.

The use of fossils in geology being thus limited and clearly defined, a large part of the science of palæontology, or the study of the old and now extinct races (παλαιων 'οντων λογος, an account of ancient organisms), reverts to zoology and botany, and ceases to belong properly to geology.

Here, as in various departments, geology makes use of generalizations obtained from other sciences; and the study and determination of all special details must be referred to the naturalist who pursues that particular branch. The doubtful mineral must be analyzed by the chemist, or measured by the crystallographer; and the doubtful bone or shell examined by the comparative anatomist, or the conchologist. But the geologist, receiving sound information from a sister science, brings it to bear on his own pursuit, and is thus enabled to identify and compare rocks found in distant lands, and also to understand and translate the dark pages of the earth's history, written in organic forms, which thus represent a true picture-language peculiar to his science.

The question of classification in geology is perhaps the one in which the use of fossils is most marked, and it depends on the grouping of animals and the distribution of groups in epochs as already alluded to. It requires, also, that we should understand the necessity of a lapse of time so large, that many readers will think it extravagant and unreasonable to account for observed phenomena in a rational manner.

If, however, it is true, as has been stated, and is now well known by the most decisive proof, that rocks contain, in such abundance as often to be entirely constructed of them, fragments of animals and vegetables, and that such fragments are distributed,

not in mere heaps, but as a constituent part of mountain masses, many thousand feet thick;—if, on proper examination and comparison, there are found to be marked differences of structure peculiar to each group;—if, also, the study of these varieties teaches that, although countless multitudes of animals and races have lived and died, there has not been any essential difference in plan from that now followed with reference to our earth;—if we find that of these similar yet distinct groups, however numerous they may be, each one requires, as far as we can judge, a long time to complete and displace,—then must we conclude that the system of this world on which we live is one not only of inconceivable magnitude and most complicated detail, but that its history runs over a period which no imagination can conceive, but which, vast and almost without limit as it may appear to us, is yet to be regarded as a definite and perhaps a small portion of a system larger, and still of more considerable duration.

Law of Distribution of Organic Beings.—When we endeavour to form a distinct conception of what might happen, during a long period of time, by the continued action of causes of change whose present amount admits of any estimate, there would seem no great difficulty in calculating, by simple multiplication, the possible results that might be attained. When, however, we introduce into the problem various complications involved in considering the mutual influence of animals and plants on each other and on climate, and still more when we consider the inverse problem of the influence of change of climate, without change of place, on the various natural tribes, we require to make a different series of observations, and to comprehend and apply different methods of reasoning.

The effect of the lapse of time on the various races of animals and vegetables inhabiting our earth, is not to be determined by any observations, however minute, of any one individual; and being mixed up with and affected by many influences, produced by modifications of climate and other physical modifications constantly going on around us, this department of science was altogether neglected, until the great discovery was made, that the remains of animals found fossil belonged, for the most part, to unknown species, nearly allied to, but unquestionably distinct from, those now existing. This naturally directed the close attention of naturalists to the determination, as far as possible, of the causes and conditions of change.

The study of the habits and structure of existing animals and vegetables, with reference to their actual adaptation to special conditions, seems to be the first step in making out the question at issue; and the method of analogy discovered to be applicable in recent cases may, with some degree of reason, be applied to determine the ancient succession, if, on discovering its true nature, we perceive that it is based on the uniform action of some general law.

Something of this has been already alluded to, when speaking of the recognised principle of representation in existing nature. The reader need only be here reminded, that in distant countries, with climates somewhat analogous, and in important respects similarly characterized, there are plants and animals nearly allied to one another, but not identical, although performing the same part in nature; whilst under other circumstances there are resemblances in appearance, and in some important general characters, without any distinct alliance or affinity.

It was also mentioned that this law of distribution, as far as it can be determined, is equally applicable in vertical and horizontal space; in other words that height above or depth below the general level of the sea, as it is accompanied by a change in climatal condition, and a diminution of mean temperature, is also characterized by a change

of inhabitants resembling that observed in countries having a different and a higher latitude, or in colder seas.

In order to understand fully the conditions on which depend the prevailing character of the flora and fauna of a spot—or, in other words, of the races of vegetables and animals found there, we must take into account all the circumstances that affect these organic bodies. It is not alone the climate that affects them—far less is it the mere temperature. The distribution of the temperature, the degree and distribution of moisture, the quantity and distribution of light, heat and air, the nature of the soil, the form of the land, and a thousand other conditions, all have influence; and it is also well made out, that in many cases when a change takes place with regard to one important species of animal or vegetable, the whole condition is altered. In applying our knowledge of recent natural history to the past, it may be said, as a preliminary remark, that "the definite notions which we may attain, concerning the general plan of creation by the study of fossils, are only valuable so far as they can bear comparison with observations concerning existing nature and the present condition and relations of organic and inorganic matter."* It is in carrying out this view, and in connecting the present course of nature with the past as determined by important existing records of species now extinct, that we are able to discover the nature of that system of representation and apparent succession which appears to afford the only key for the solution of the innumerable difficulties presented in investigating the relations of species, some of which are nearly allied to each other, but not analogous—others strictly analogous, but having no affinity.

Looking around us at the animals and vegetables now occupying the land and waters in the eastern portion of the northern hemisphere, and comparing these with the inhabitants of the corresponding parts of America, this principle of adaptation may be in some degree appreciated by every one. But we must learn much more than is known at present concerning the powers of endurance and adaptation of different races, before we can positively assert the extent of change that would be produced by any slow but important modification of climate.

A knowledge of the differences observable in the inhabitants of distant spots will assist in this investigation; and we may perhaps conclude that, whatever the law of analogy may prove to be at present, the safest and best course must involve the hypothetical application of the same principle to the geological problem, before any other theory can be admitted as worthy of consideration.

If we take a limited district, characterized now by certain botanical and zoological peculiarities, and apparently the centre or metropolis of certain species which are there presented in their most typical form, there may exist immediately beneath, if not actually upon the surface, remains of vegetables and animals presenting on the whole a different aspect—remains, too, which we can discover to have been the inhabitants of the district at some immediately antecedent period. We may find very nearly the same difference, if we compare this district with some other at a distance, or with one in which the conditions of temperature are widely different, in consequence of the land being at a higher level above the sea, although in the same latitude. And this is what is meant, when we say that the various races of animals and vegetables have been distributed in time as they are distributed now in space—changes arising from lapse of time producing results in reference to representative species, similar to those effected by the introduction of races adapted to similar conditions, but situated in distant regions.

* Ansted's "Ancient World."

Law of Development.—It has been long a subject of speculation among naturalists, how far the modifications, by which different species of animals seem to be derived one from another (those of more complicated organization being elaborated in course of time from more simple forms), may be really the result of some natural law of development, and not due to successive creations, each requiring the exertion of a special interference of the Author of nature. Without at all entering on a discussion of this question in the abstract, which would here be out of place, it yet falls within the proper limits of our subject to make a few remarks relative to this question.

The argument is thus briefly stated. That since it appears, from what we know of natural history in general, that the whole number of varieties of form observable in nature pass into and from one another by gradations always very close and sometimes obscure and hardly traceable; since, also, many modifications of specific form are undoubtedly produced by time and by long exposure to special modifying conditions; and since there is a general parallelism and resemblance traceable in different groups throughout nature; therefore it is probable that according to some law, of which at present we know nothing more than these supposed effects, species are capable of occasionally producing, by the ordinary means of succession, other species differently organized, which, once established, occupy new ground, and become themselves the starting point for new changes.

Now, so far as geology is a guide in teaching us the law of succession of species, this idea is entirely unsupported, and it would seem to derive as little assistance from the minute study of existing nature.

It is indeed true that in general the order of succession in time has been from the less to the more perfectly organized groups, so that in the earliest periods of the earth's history the seas were inhabited chiefly or only by invertebrated animals, and afterwards by fishes. We have no right to assume, however, the total absence of reptiles and mammals at these early periods, for we have no positive evidence on the subject, and the negative evidence is very imperfect. And with respect to the invertebrata and fishes, it is by no means the case that those least perfectly organized were the first introduced. So far indeed is it from being so, that among the earliest known of all created beings occur species referred to the most highly organized group of invertebrated animals, those resembling the cuttle fish of the present day; whilst amongst the articulated animals are the trilobites, provided with eyes as perfectly and beautifully organized as those of the dragon fly. At the earliest introduction of fishes we find the voracious and highly organized tribe of sharks fully represented; and another tribe, more nearly approaching the reptiles, was then far more abundant than at any subsequent period, and is now extremely rare.

A SILURIAN TRILOBITE (*Trinucleus pongerardi*).

To sum up this subject in a few words, it is only needful to recount some of the principal indications of change at present proved with regard to the condition of the earth's surface, and the animal inhabitants and plants found in different parts thereof.

It appears that not only are there proofs sufficiently distinct, that the whole face of the earth is gradually undergoing change; that the hills are being ground down and reduced to a lower level; the coast lines altered; extensive tracts of land elevated in one district and depressed in another; but also that the inhabitants of the land are likewise undergoing change corresponding, it may be, with the modifications of the land and sea-bottom; but still, no doubt, governed by independent laws, and producing most important results.

For what do we find? At no distant period, even in our own island, there was a country partly covered by thick forests, partly abounding in caverns, affording shelter to wild animals, and tenanted by the lion, the bear, the wolf, and the hyæna; while an elephant, two species of rhinoceros, many cervine animals, and amongst them the reindeer, and another species of deer, gigantic in size, and with horns expanded in still grander proportions, together with the wild urus, now confined to the forests of Eastern Europe, and many other ruminating animals, peopled the plains, and wandered at liberty through the country. In the rivers, also, were then found the hippopotamus and the beaver, associated with the otter, which still remains. Here, indeed, is a condition of things singularly unlike that which now exists, and we may suppose it unequalled elsewhere. But such is not the case. At about the same time, and therefore very recently, compared with the distant periods which we shall have to consider in continuing our investigations, the country which is now India was peopled likewise by a group of animals different from the present races.

In South America the tribe, of which the sloth, the armadillo, and the ant-eater are all that now remain, was then represented by the megatherium, the glyptodon, and others. In Australia were gigantic kangaroos; in New Zealand equally gigantic wingless birds; and probably in other parts of the world similar strange modifications. And these are the first steps in passing from the present to the past. These steps are so clearly marked, they belong to a period comparatively so modern, yet at the same time they involve changes so considerable, that it seems almost equally difficult to admit the conclusions which immediately result, or to question facts so exceedingly manifest. And yet these, strange as they are and difficult to comprehend, are yet only the first and the simplest steps in geology. Once launched into the science, and when we have learned to contemplate it in its simplicity and grandeur, as the history of nature from the beginning of the existence of matter and life, we soon find that these changes, however great, are but the last of a very long series, each in its turn involving the introduction, the arriving at maturity, and the gradual but sure decay of whole groups of animals and vegetables, no doubt perfectly adapted to the circumstances in which they were placed—each the record, the hieroglyphic, marking one chapter of the history; and what is most marvellous of all, each handed down, in spite of all change, to communicate this history by legends admitting of no misconstruction, and capable of being fully comprehended and translated into his own language by the intellect of man.

Classification of the Stratified Rocks.—Making use of fossils in the manner above indicated, and bringing together the facts observed in various parts of different countries throughout the world, we find that the stratified rocks admit of being grouped, first, into three well-marked series, separated from one another by very remarkable natural-history peculiarities, and, afterwards, that each of these three is capable of subdivision, very distinct in particular countries and localities, but not so easily noticed, when we compare together the geology of places widely removed in distance, whether

of latitude or longitude. The three principal groups of rocks are now commonly spoken of as—1. the PALÆOZOIC, or older group; 2. the SECONDARY, or middle group; and 3. the TERTIARY, or newer group. Other names are occasionally used by geologists, both of this and other countries; but it is unnecessary to detain the reader with any account of them in this place. The French and Belgian geologists, and sometimes others, admit of a fourth division, to include more recent rocks than the third group; but this also seems unnecessary.

TABLE OF CLASSIFICATION OF ROCKS.

I.—TERTIARY EPOCH.

Superficial Deposits.—Raised beaches—peat bogs—submerged forests—mud deposits in caverns—shell marls and modern deltas.

Upper Tertiary.—Gravel beds—Till—mammaliferous crag of Norfolk—red crag—upper limestones of Sicily—subapennine beds—loess of the Rhine valley—brown-coal of Germany—uppermost fossiliferous beds of Northern India (Kunkur, &c.), South America, Australia, and other countries.

Middle Tertiary.—Coralline crag—upper molasse of Switzerland—crag cliffs of the Loire and Garonne—tertiaries of Vienna—numerous beds in India and America.

Lower Tertiary.—London and Hampshire clays and sands—Isle of Wight beds—beds of the Paris basin and Brussels—lower molasse of Switzerland—lower beds of Sewalik Hills, India—nummulite and other limestones of the Eastern Mediterranean.

II.—SECONDARY EPOCH.

Upper Secondary, or *Cretaceous Series.*—1. Chalk of England, France, Belgium, and Denmark, *scaglia* of Italy—2. Lower chalk and chalk marl, *quadersandstein* of Germany—3. Upper greensand or firestone—4. Gault—5. Lower greensand or neocomian.

Middle Secondary—*a. Wealden Series.*—1. Weald clay—2. Hastings sand—3. Purbeck beds.

b. Oolitic, or *Jurassic Series.*—1. Portland beds, and lithographic beds of Bavaria—2. Kimmeridge clay—3. Coral rag, and nerinæan limestone—4. Oxford clay—5. Cornbrash, Forest marble, Bradford clay—6. Great oolite, Stonesfield slate, Fuller's earth—7. Inferior or Bath oolite.

c. Liassic Series.—1. Alum shale—2. Marlstone—3. Lower lias shales.

Lower Secondary, or *Triassic Series.*—1. Upper new red sandstone, keuper or variegated marls—2. Muschelkalk (absent in England)—3. Variegated sandstones, Bunter sandstein, or gres bigarré.

III.—PALÆOZOIC EPOCH.

Upper Palæozoic, or *Permian Series.*—1. Magnesian limestone—2. Lower new red sandstone.

Carboniferous Series.—1. Coal measures—2. Millstone grit—3. Carboniferous, or mountain limestone.

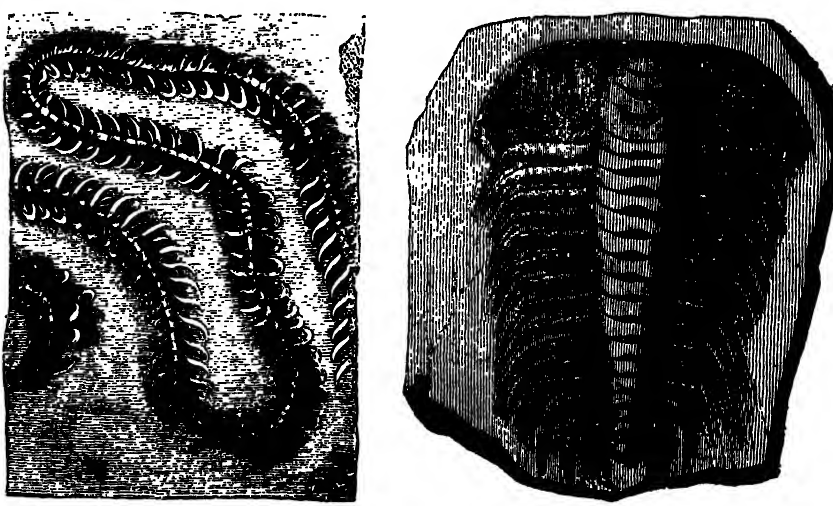
Devonian, or Old Red Sandstone Series.

Silurian Series.—1. Upper Silurian (Ludlow and Wenlock groups)—2. Lower Silurian (Caradoc sandstone and Cambrian rocks).

The subdivisions will be referred to in some detail in the following pages; and at present they are merely given in a tabular form for the convenience of reference. In the foregoing table the newer or more recently formed beds are placed first; but it will be convenient to begin the description with those of oldest date, thus tracing the earth's history from its commencement, and passing on by successive steps to those rocks of more recent time.

PALÆOZOIC EPOCH.

Lower Silurian Rocks and Fossils.—Reposing on crystalline or metamorphic rocks, in which no fossil remains have yet been found, there have been traced in Wales, Cumberland, the south of Scotland, and various parts of Ireland, in the west of France, the north-west of Spain, the islands and shores of the Baltic, in Bohemia, in the Hartz, in many parts of eastern North America, on the western side and plateaux of the Bolivian Andes, in Brazil, in South Africa, and in Australia (?), a series of rocks, more or less altered, belonging to the lowest fossiliferous series, and containing fossils all sufficiently similar to justify their being referred to the same period. The deposits are chiefly sandstones, but include extensive ranges of slate and some bands of limestone, both thick and widely spread, though small in proportion to other rocks. The Caradoc sands and Llandeilo flags of Wales, the schists and psammites of France and Belgium, the Woolhope and Horderley limestones, Trenton limestones, Potsdam sandstones, and Angers slates, are all well known and strongly marked deposits of this period. They



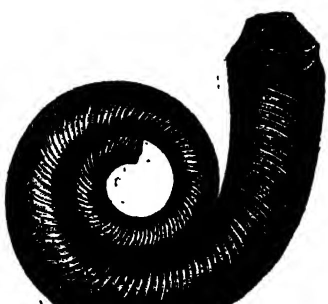
(*Nereites cambriensis.*) (*Paradoxides spinulosus.*)

FOSSIL WORM AND TRILOBITE FROM LOWER SILURIAN ROCKS.

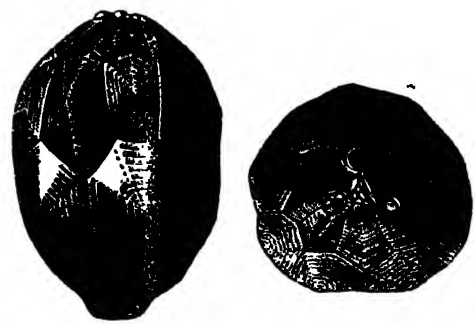
show a total thickness varying from a few hundred to as much as four thousand yards (as measured in Bohemia by Monsieur Barraude); and though often much altered, present many localities where they appear to have undergone but little change since their first deposition and hardening.

Among the fossil remains found in these ancient rocks, which have generally been regarded (though perhaps without sufficient reason) as those first formed under circumstances favourable to organic existence, may be mentioned small fishes of the shark tribe, several genera of the remarkable group of trilobites, some worms, some sea-weeds, a number of chambered shells resembling that of the nautilus, several univalve and bivalve shells, several echinoderms (star-fishes, &c.), and several of the two principal groups of coral animals. Up to the present time the other kinds of fishes, and all quadrupeds, birds, and reptiles, and a large proportion of the best known and most abundantly represented generic forms of the invertebrated animals have not been detected.

The trilobites were singular crustacean animals living in the ancient seas in great number, and capable, it would seem, of either floating with their backs downwards from the surface of shallow water, or burying themselves in mud at the bottom. Some remarkable forms of them (*Paradoxides*) were apparently very common, and are widely distributed. Among the more interesting of the fossils are markings on sandstone, showing the existence of marine worms (*Nereites cambriensis*),



LITUITES CORNU-ARIETIS.



HEMICOSMITES PYRIFORMIS.

such as those still seen on a sea-shore. There is another fossil of a singular structure (*Hemicosmites*) which appears to exhibit the earliest form of those radiated animals which have since been largely developed under every variety of shape, and are still represented on our coasts by the sea-egg, sea-urchin, &c. Lastly, the representatives of the nautilus (*Lituites*) and cuttle-fish exhibit some peculiarities of form, and though not so plentiful as in after times, are still very common in certain localities.

Many very extensive tracts, occupied with Lower Silurian rocks, have hitherto yielded no fossils whatever; in other cases organic remains are extremely rare, but there are many districts where they are very abundant. In the former case the deposits may have taken place in deep water, and in the latter near shore; and there is nothing to prove that the seas were much more extensive then than they are now, although it is not improbable that they extended in very different directions.

The modifications and metamorphoses of Lower Silurian rocks are often very considerable, clays having been converted into slates, limestones into marble, and sands into quartz rock. In the crevices are numerous veins, often containing metals, and not

unfrequently admixtures of metallic sulphurets, containing a marked proportion of gold.

Upper Silurian Rocks and Fossils.—A very important band of limestones and shales, belonging to this part of the series, was first described by Sir Roderick Murchison as occurring in Wales and Shropshire, and formed the basis of a description, which has since been referred to as the starting-point in the geology of the old rocks. The subdivisions there observed are as follow:—

1. Tilestone.
2. Ludlow group, { Upper Ludlow shale, Aymestry limestone, Lower Ludlow shale.
3. Wenlock group, { Wenlock or Dudley limestone, Wenlock or Dudley shale.

Of these beds the limestones are loaded with clayey matter, and the shales are often very calcareous, so that the whole may be regarded as an impure mud deposit which has since undergone a change. Wherever it has happened, from any cause, that numerous shells or corals have existed, these have perhaps originally mixed with the clay and mud, and since then, by a process of segregration, calcareous bands have been formed.

Elsewhere this condition of the sea was greatly different. Thus, in Westmoreland and Lancashire, beds of similar age consist of impure sandstones, while on the shores and islands of the Baltic, and in Canada, blue limestones of considerable purity prevail. A band of Upper Silurian rock also traverses the Urals, and extends parallel to the Alleghany chain in North America. In the latter case it contains salt beds.

Besides these principal developments, Upper Silurian rocks occur in Spain, France, Holland, and Germany—the Bohemian deposits being especially remarkable and interesting. Similar strata have been traced in South America, South Africa, and South-Eastern Australia.

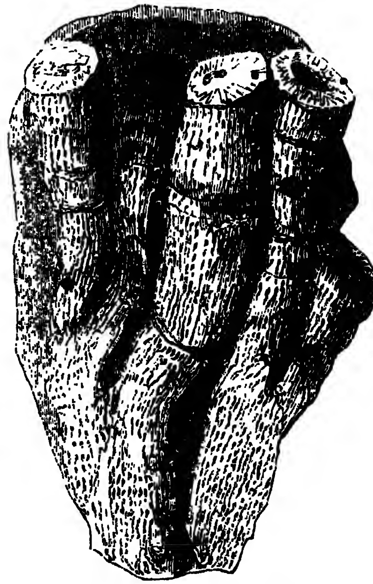
The characteristic fossils hitherto found in Upper Silurian rocks are numerous and varied. They include several trilobites (*Calymene* is a genus especially remarkable), some singular corals (*Cyathophyllum*), and several highly-interesting radiated animals (*Hypanthocrinites* and *Dimerocrinites*), besides univalve and bivalve shells (*Lingula*, *Orthis*, *Pentamerus*), in great variety. A group of these fossils is given in the following page. The trilobites (*Calymene*) are large, fine, and numerous; the shells, also, of large size, and well-marked forms; and these, as well as the encrinites, are widely distributed in similar if not identical species, occurring in England, Russia, and North America.

The remains of fishes are rare in most of the Silurian rocks, but have been discovered in some districts in considerable quantity. Thus, at Ludlow, is a fish-bone bed of this period; and elsewhere, no doubt, similar local deposits will be found.

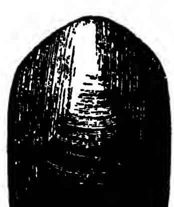
No indications of the existence of reptiles have yet been met with in rocks of the Silurian age; but this is no proof that such remains may not hereafter be found.

Reverting to what has been said of the mechanical as well as chemical condition of stratified rocks containing no fossils and often greatly altered, and also of those unstratified rocks beneath or otherwise in contact with them, we may now endeavour to picture to ourselves the earliest state of the earth, as far as it is revealed by observation, and by the fragments of organic life that have escaped the numerous chances of destruction.

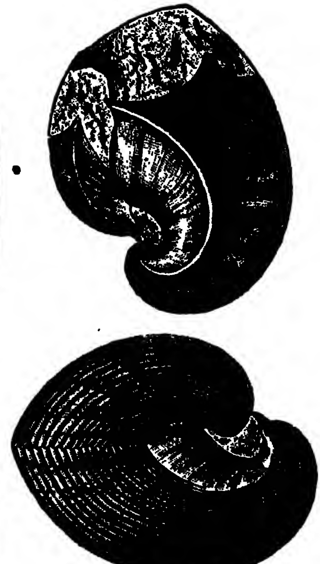
HYPANTHOCRINITES DECORUS, AND DIMEROCRINITES ICOSIDACTYLUS.

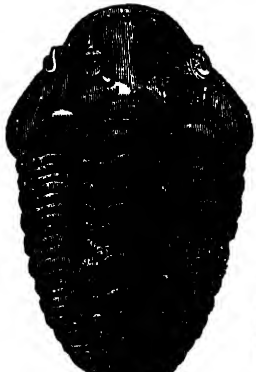


CYATHOPHYLLUM CÆSPITOSUM.



LINGULA LEWISII.





CALYMENE BLUMENBACHII.

ORTHIS RUSTICA.

PENTAMERUS KNIGHTII.

Judging partly from the general appearance of the various bodies of the solar system and from astronomical considerations, and partly from the appearances presented by the various rocks at and near the earth's surface, it is supposed that at a very early period of its history our globe may have existed as an intensely heated body, in a fluid or molten state, and that it gradually cooled at the surface, perhaps by exposure in space, contracting in dimensions as it cooled and hardened. In this manner, it may be, a succession of thin solid films or crusts were formed; each one, as soon as formed, beginning to shrink and crack, until at length, after a number of such broken crusts had been produced, a certain balance was attained between the thickness of the crust, the rate of cooling, and the amount of internal heat. This would not have taken place until the production of a rough, uneven surface, having many elevations and depressions, nor until the temperature had been sufficiently reduced to allow of an atmosphere, and permit the permanent presence of water reposing in the hollows, and forming seas and oceans. Until the time when water could exist, without being converted into steam, we cannot imagine the possibility of any organic beings existing either upon or beneath the surface, although at any temperature, below that of boiling water, both vegetable and animal life is possible, even under the limitations with which we are familiar.

Thus, then, according to this view, the first period of the existence of the earth, as a planet, was marked by a chaotic state of igneous fusion, and characterized by frequent disturbances of the surface, the effect of contraction during the cooling of the successive films or pasty crusts of oxidized and half solidified rock. As soon, also, as water was present, we may suppose that its action would be exerted in grinding down, and depositing in a mechanical form, the detritus of the older and igneous rocks; and in this way we seem best able to account for the nearly uniform character of the ancient granitic rocks, and those most directly associated with them in various distant parts of the globe.

In the mechanical rocks derived from the early granites, we have, therefore, a second epoch of the earth's history still unmarked by life, although apparently somewhat better fitted for sustaining it. At this time the earth was no longer a mere chaotic mass of cracked and burnt rock; but there existed, superimposed upon that mass, extensive and thick layers of material, which, although derived from granites, contained most of those elements, both gaseous and solid, by certain new combinations of which animals and vegetables, when once endowed with life, are enabled to perform their functions, and render inanimate matter available for all the purposes of living beings of higher organization.

One of the most remarkable facts, with regard to these ancient deposited rocks, is their extraordinary thickness in some districts, and the broad tracts over which they are occasionally spread. It is not, indeed, very difficult to see why, when the granite and granitic rocks were newly formed, and presented a multitude of recently fractured edges in every direction, the pounding action of moving water, perhaps at a high temperature, might not grind down the exposed surface with extreme rapidity, and filling up the hollows and depressions, produce extensive deposits. But we can hardly suppose the existence of depressions so considerable as the actual thickness of these altered rocks would require, and it is more reasonable to assume that during, and in consequence of, the gradual cooling, the contraction of the crust would produce puckering and wave-like plications of the surface, alternately elevating and depressing particular districts, and occasionally, perhaps, producing a succession of elevations or depressions

on the same spot. Whether this were so or not, it is at any rate probable that these old sedimentary masses may have been exposed to the action of long-continued heat in many cases, so that they have become actually crystalline; and they have also been often cracked and broken into fragments, the cracks being filled with rocks of a different kind. In addition to these, there have been produced a vast number of other changes; some of them, it would seem, involving a considerable lapse of time, others vast mechanical force, and others again great chemical action, connected with an important development of electrical and polar forces.

These lowest and oldest of the sedimentary strata, whose antiquity is in many places unquestionable, which repose on the bare skeleton—the rocky framework of the earth—thus occupy a fixed, a prominent, and an important place among the rocks of which the earth's crust is made up. They also mark a strange and dark passage from that state which has been mentioned as chaotic to a condition of regular and quiet deposit; they are, however, so far as we can tell, and with reference to other rudimentary rocks, *azoic* (lifeless); but they form a class almost as widely spread, and as distinctly universal, as the granitic rocks themselves.

We suppose, therefore, that at the end of the first great period of the earth's history, it existed as a globe, perhaps of somewhat larger dimensions than it is at present, but still partly covered by water, and surrounded by an atmosphere. Of the land that rose above the surface of the water, some portion even then exhibited a distinctly stratified appearance, and the thick masses of strata rested on huge bosses and peaks of granitic rock newly forced up by constant heavings of the liquid fire beneath. On their surface, however, all was then bare and desolate—not a moss, not a lichen covered the naked framework of the globe; not a sea-weed floated on the broad ocean; not an animalcule was present in the whole of the wide expanse—all was still, with the stillness of absolute death. The earth was prepared, and the fiat of the Creator had gone forth; but there was as yet no inhabitant, and no form of life had been introduced to perform its part in the great mystery of creation.

There was, however, we may be assured, no long interval between the moment when organic life could exist, and that in which various tribes were introduced, adapted to the peculiar conditions of the land and water. The early Silurian animals already alluded to were, it is supposed, among the first, if not the very first created; and among the groups already known, we find that tribes exhibiting the lower degrees of organization generally preponderate so far as to be really characteristic. Thus, for example, in the lower Silurian rocks are described some fucoids or sea-weeds, not a few plant-like animals, scarcely removed from the sea-weeds in point of organization, a few corallines, and some stony corals, together with a vast multitude of encrinites, or stone-lilies, and a few straggling star-fishes. The present crustaceans (crabs and lobsters) were represented by the trilobite, the pretty sea-shells found on our coasts by the sluggish terebratulæ, and the most voracious of the fishes by the nautilus and cuttle-fish, or at least by nearly allied animals of this kind, some of them of very large size. The genera now common were then rare—some of those now rare, were then common; but most of the generic forms, and all, without exception, of the species, resembled existing animals only by analogy. Quite at the close of the period, and not till some thirty or forty thousand feet of strata had been deposited in one spot, a few fishes' remains appear, but they nowhere seem abundant. They were very small in size, but ferocious and predaceous in their habits, and allied to the present shark tribe.

It appears, then, on the whole, that almost all the great natural groups of inver-

tebrate animals and fishes were represented in these earliest beds, and commenced their course on the earth at the same time as the most minute sea-weeds and zoophytes. There is nowhere any appearance of progressive improvement—the encrinite succeeding the coral animal, the trilobite coming in at the close of the encrinite period, the terebratula succeeding it, and eclipsed in its turn by the nautilus. The whole number were contemporaneous, and formed a group doubtless adapted, in the best possible way, for the condition of the earth's surface at that time. The difference of organization presented by these animals, when compared with those now living, is also small, and we are not at all justified in assuming a higher or more uniform temperature to have existed, or that there was a more widely extended sea, a different atmosphere, or other modifications beyond those readily producible by changes in the relative position and extent of land and sea.

Neither does the absence of certain races of animals, which in later times were amongst the most numerous, lead to the conclusion that any very different conditions existed in the ancient sea from those now obtaining, nor would their mere absence enable us to form any notion of the cause. It is because we find a number of animals manifestly *representative*, and evidently adapted to perform the same part in creation as those now existing, that we fully see the nature of this difference.

Still, no doubt, the condition of the Silurian ocean would have a strange aspect. With something of resemblance to the modern seas, in the numerous reefs and islands of coral constantly rising to the water's edge, and then soon destroyed by the gradual enlargement of a rising continent—with resemblance also in some of the shells of the coast-line and the open sea—there would yet be much very different and new. The muddy and sandy shallows would have their peculiar inhabitants, and the deeper banks would be covered with trilobites; while myriads of these unsightly animals, some of them of gigantic proportions, would float in clouds in the water, seeking food, swimming with their backs downwards, and ready to sink to the bottom at the slightest approach of danger. Farther out at sea, and attached to the rocky bottoms, we should have the elegant forms of the sea-lilies waving their living stems and branches, and stretching out their stony net-work to entwine and appropriate whatever came within reach. Darting through the water in every direction, and of almost every size, the voracious cuttle-fish of that period would devour the softer and crush the harder parts of almost every species then living, and perhaps of the less powerful individuals of their own race. Some of these—two, or even three feet long, spear-shaped, with large fins and long spreading arms, terminated with the most frightful weapons—must have been the tyrants of the deep; while others, of a rounder shape and less active habits, would have little chance of escape, except in the power they possessed of instantaneously dropping to the bottom, and perhaps hiding themselves in the mud.

Devonian or Old Red Sandstone Period.—In Devonshire and Cornwall, on the Rhine and in various other parts of Western Europe, in Eastern Europe and some parts of Asia, and again in many places in America and the large islands of the Southern Ocean, there are found very extensive deposits, consisting of sandy and muddy beds, overlying the Silurian rocks, which thus pass insensibly into these beds of a newer period. Elsewhere in England, in Scotland, in some parts of Russia, and America, the close of the Silurian period was succeeded by a time when a vast mass of rolled material, consisting of quartz pebbles and other fragmentary rocks, was deposited in a spot now forming part of Scotland, and in what is now Herefordshire. Most probably the deposit of this vast mass of detritus, with occasional bands containing

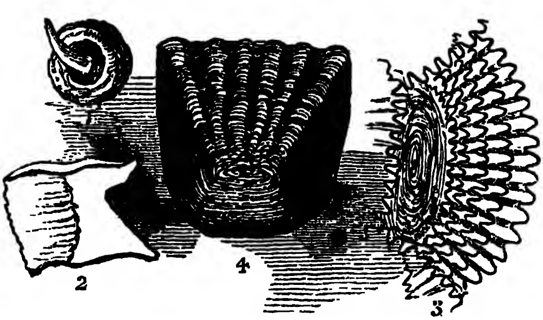
numerous remains of fishes, was one consequence of a considerable upheaval of land in the northern hemisphere, producing a succession of resistless waves, which not only swept along the gravel but shaved clean the surface of the rocks they passed over.

In this way were formed the contemporaneous deposits of the *Devonian rocks* and the *Old red sandstone:* the former muddy and calcareous, containing corals, shells, and trilobites; the latter sandy and gritty, and, where exhibiting fossils at all, having chiefly the remains of fishes.

It seems likely that the whole, both of the Silurian and Devonian period, was marked by the elevation of European land, and perhaps also of land in North America, Australia, and elsewhere, where these rocks occur. That such a view is correct seems probable, partly because all the coral banks of the period must have been fringing reefs, and partly because of the amount of volcanic action known to have been going on in our own country and elsewhere at this time. In the same way, too, it seems easiest to account for the conglomerate of the old red sandstone, which may possibly have been drifted into hollows, and thus have obtained the vast thickness sometimes observed. But the elevations must have been numerous, and perhaps accompanied by corresponding and not distant depressions, in order to produce some of the phenomena of this singular period.

During the Devonian period there existed in the seas a number of fishes of a very remarkable kind, in addition to a multitude of less highly organized animals resembling the Silurian groups. These fishes are interesting, not only as giving us an insight into the condition of the ancient seas in this respect, but also in their comparison with existing species.

At the present time there are various ways of grouping the different tribes of fishes; and these, of course, depend on some characteristic peculiarities of structure. Taking, however, all known forms, extinct as well as recent, it is found that the skin, or rather the hard covering of the skin, corresponding with the skeleton of less highly organized animals, affords a character which may be made extremely useful, if it be not actually sufficient. Thus almost all the different kinds of fishes have scales; and these are either coated with enamel, such as the skate, the shark, and the sturgeon, or are comparatively simple, not being coated with any hard substance, as is the case with the common fishes round our own shores. There are four principal varieties of the structure of the scale, two belonging to each of the above peculiarities; and though at present but few of the fishes can be referred to the first two, yet, on the other hand, almost all those found fossil in the older rocks are of these kinds.



SCALES OF FISHES.
1, Placoid; 2, Ganoid; 3, Ctenoid; 4, Cycloid.

The annexed diagram will show in some degree the state of the case. The small hooked scale represented in No. 1 is that belonging to a group of which the shark is a well-known instance. Sharks are now by no means rare; but in ancient seas, especially

those of the earliest epoch, they were incredibly abundant. The scale No. 2 is singularly different, because, though hard and bony—the bone on these surfaces resembling that of the tooth rather than any other kind in its closeness of texture—it is smooth and angular; forming in the bony pike (a singular North American lake fish) a complete and connected coat of armour of the most perfect kind. The animals thus clothed are now extremely rare, but in the ancient seas were the common, if not exclusive, inhabitants.

TAILS OF FISHES.
1, Shark; 2, Trout; 3, Wrasse.

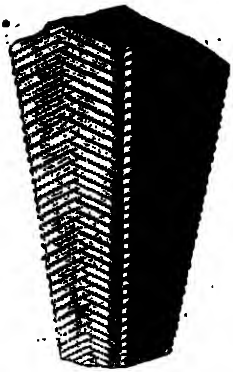
On the other hand, in Nos. 3 and 4 we have figures of the scales of fishes now familiar. Of these the perch, with its comb-like fringe (3), is the representative of one large group; and the salmon, having a smoother and more rounded and entire margin (4), of another equally large and now no less important. Of the fishes having these two kinds of scales not one representative has yet been found in the older rocks; and although it may be that large numbers of species less defended with bony armour have been destroyed in the lapse of time and by numerous accidents, it is yet unlikely that, where so many far more delicate and more easily-injured animal substances have been preserved, some at least of the scales should not be met with. Such, however, is the case; and, practically, we have only to deal with the two first-named divisions of fishes in the Palæozoic epoch.

Another peculiarity of fishes that has been noticed is the mode in which the body is terminated and the tail attached. In the shark, and generally in the placoid and ganoid fishes, the back bone is continued into, and forms part of, the tail, which is thus unsymmetrical (see annexed woodcut, Fig. 1); while in the modern fishes, in most cases, the tail is a mere fin, either double, as in the trout (Fig. 2), or single and rounded, as in the wrasse (Fig. 3)—a common fish on the English coast, sometimes called *old wife*. Here, as in the scales, a marked difference exists between the prevailing form in modern and ancient times. All the old fishes have tails like the shark; most of the modern ones resemble, in this respect, either the trout or wrasse.

During the deposit of the rocks of the Devonian period several very odd and uncouth fishes, covered with bony framework, and belonging to the ganoid division, not only existed, but appear to have been the almost exclusive inhabitants of the deep. Of these the figure of the Pterichthys (wing-fish), as given in the annexed group of Devonian fossils, is itself sufficiently curious. This animal was one of a group remarkable for the large size of the bony plates compared with that of the animal, and also for the distinct and peculiar forms of such plates. There were also bony coverings to the fins, and a projecting tail, giving the appearance of a winged animal, although there cannot be a doubt that the fish-like character was perfect. Several species, also

enveloped in hard cases, but more like the existing tribes, accompanied the pterichthys; and there was also one, the *Coccosteus*, so called from the berry-like tubercles with

GROUP OF MIDDLE PALÆOZOIC FOSSILS.

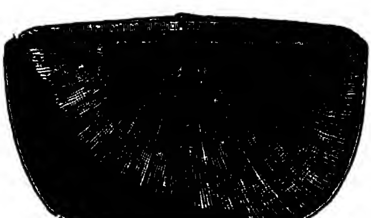


CONULARIA ORNATA.

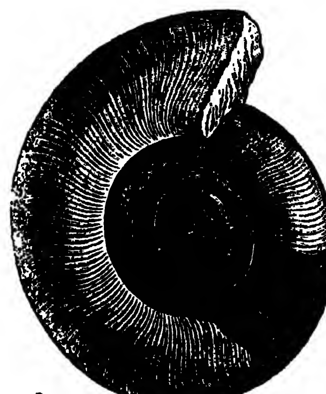
AULOPORA SERPENS.

TURBO SUBCOSTATUS

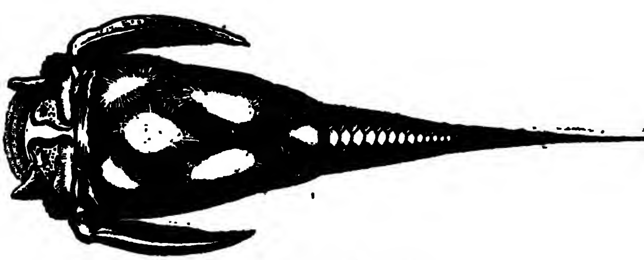
PENTREMITIDEA SCHULTII.



LEPTÆNA LEPIS.



CLYMENIA SEDGWICKII.



PTERICHTHYS CORNUTUS.

which the large bony plates were covered, and of which numerous fragments have been obtained, chiefly from the flagstones and other beds of the old red sandstone of Scotland.

Another group of these ancient fishes is remarkable for the great magnitude of the fins, and the fact that those fins on the back and below the tail are double.

The jaws of most of these animals are provided with sharp-pointed teeth. The head was, as it were, inclosed in a cartilaginous box, coated with enamel; and the scales on the body are sometimes so disproportionately large, that they do not exceed six in number between the head and tail. These fishes probably swam more rapidly, and perhaps inhabited deeper seas, than the others; but they were of small size, and but a small number of genera have yet been detected. Similar tribes of larger size, and more powerful, appeared towards the close of the period.

Although, in the nature of the mineral accumulations during the Devonian period, we seem to have an intimation of the existence of land near our present coast-line in various parts of the world, yet there is none of that evidence which the actual existence of the very inhabitants of land gives, until we reach quite the close of the period, and come to the carboniferous rocks. In Devonshire, indeed, and perhaps in Ireland and elsewhere, vegetable fossils are found in the older shales, marking the spot where land first appeared; but these must be regarded as exceptions to the usual condition.

We are not, however, to suppose that, because there is for the most part an absence of land fossils in the Devonian rocks, there was therefore little land at that time above the surface of the sea. Nothing can be more likely to lead to error than this hasty judgment from first impressions; and in the case under consideration it is most likely that, during the whole of the Silurian and Devonian period, land had been increasing in the northern hemisphere—that at the close of the Devonian period it attained a maximum, and that immediately afterwards it began to sink. But this early land was not placed where we can now find actual traces of its existence. Perhaps it was a first Atlantis, occupying a vast space now covered by the great Atlantic canal separating Europe and America. It is, however, possible that a portion of Northern Europe was even then elevated above the sea, and formed dry land.

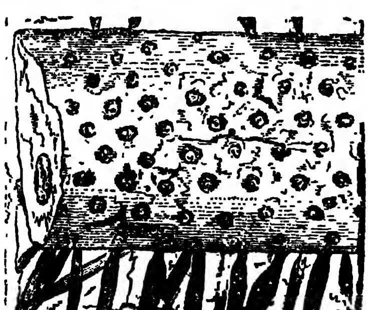
Rocks and Fossils of the Carboniferous Period.—The first great indication of change that presents itself, with regard to the movements then going on, is seen in the formation of those mountain masses of coral found in various places, not only in England, but in other parts of Europe, and in America. These afford proof of a series of alternations of level; and the presence of vegetable fossils, sometimes associated with the limestone, show that there had already commenced that abundant vegetable life so characteristic of the later portions of the carboniferous period.

The *Carboniferous* or *mountain limestone* may properly be regarded as the base of the whole carboniferous series, although in Ireland there is a peculiar sandy deposit, and in many other parts of Europe a dirty shale between the limestone and the Devonian rocks. Few geological formations are more marked or more uniform in their peculiar characters, and none is more important, in an economic sense, than the carboniferous series; and, as the ordinary basis of this series, the carboniferous limestone possesses great interest. Most of the limestones of this period are either coralline or derived from the fragments of marine animals of other kinds, and intimately associated with coral. They are therefore essentially fossiliferous. Their thickness varies, but often amounts to a couple of thousand feet, and the rock is usually hard, considerably altered from its original condition, and contains in its crevices numerous crystalline minerals and ores of lead and zinc, with other metals. In picturesque features it is also well marked, as it is frequently abrupt and fragmentary in its appearance, with fine escarpments, lofty cliffs occasionally overhanging, and a rough, weathered surface.

With such features the carboniferous limestone is recognised in Derbyshire, Devonshire, and Yorkshire, and in North Wales. It is reproduced on the Continent, in the upper valley of the Meuse, and in some parts of Russia, and again in Canada on the western shores of the Atlantic. In a less picturesque form, but still perfectly recognisable, it occupies large tracts in Ireland, Germany, and the western states of the Union in North America. It everywhere abounds with fossil remains, many of them extremely interesting. The adjoining page contains a number of these.

Above the carboniferous limestone a deposit of hard coarse sandstone supervenes, frequently, in England, of such a nature as to be valuable for millstones, and thence called *millstone grit.* It often contains bands of coal, though these are usually thin and of small value. It is a somewhat local deposit, being almost confined to England, and forming indeed little more than a sandy base of the coal measures. It contains no characteristic fossils.

Next in order comes in that great and important series of sands and shales whose association with available mineral fuel render them of infinite value to every country in which they are found. These beds, called the *coal measures,* are often the only, as they are always the most essential, representatives of the great carboniferous series, whose title is hence derived. They are widely distributed in England, Wales, Scotland, and Ireland; in Belgium, France, and Spain; in many parts of Western Germany; in Bohemia, Saxony, and Silesia; on the banks of the Don, on the shores of the Black Sea, in various parts of Asia and in the islands of the southern seas. Similar deposits

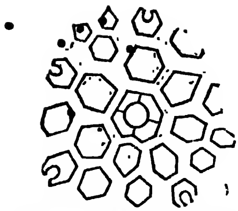


STIGMARIA FICOIDES.

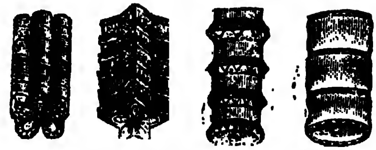
PORTION OF A CALAMITE.

of the same geological age, and of still greater extent, occur in several parts of North America, both on the eastern side and in the great Mississippi valley. Throughout these wide tracts available mineral fuel occurs in association with peculiar shales and grits, and always with the same association of vegetable remains. The nature of that part of the vegetation of which fragments are preserved is very peculiar; but it is important to bear in mind that in such matters the absence of certain forms affords no real proof of their not having existed, unless we are also able to determine actual proofs of the existence of others representative of them.

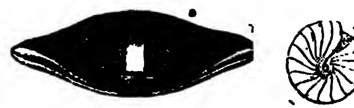
SPHENOPHYLLUM DENTATUM.



CYATHOCRINUS CARYOCRINOIDI



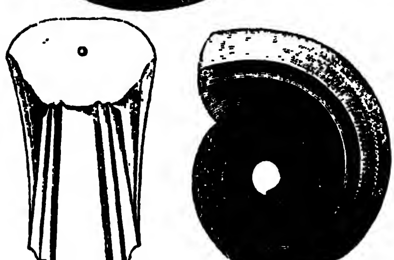
ENCRINITAL STEMS.



FUSULINA CYLINDRICA.

CHONETES DALMANIANA.

LIMULUS ROTUNDUS.



NAUTILUS KONINCKII.

BELLEROPHON.

ORTHOCERATITE.

SPIRIFER HYSTERICUS.

In addition to the usual clays and sands, which formed the ancient land and sea bottom of the carboniferous period, and in which are often found the trunks of trees buried with their roots, or standing upright, turned into or incased with stone, it is not unusual to meet with very coarse conglomerates in the coal measures, with which fine bands of pure limestone occasionally alternate. Thus, at Ardwick, near Manchester, is a fossiliferous band of this kind; and another at Burdie House, near Edinburgh, presents numerous organic remains, chiefly of fishes. It also occasionally happens that sandstones of various degrees of coarseness form almost the only materials associated with the coal.

The coal measures and underlying beds have been so greatly and repeatedly broken asunder, and shifted from their original position in England, where coal was first extensively worked, that such disturbances of stratification have often been regarded as essential to carboniferous rocks. No opinion can be more erroneous, as there are vast tracts in many districts where the coal is very little inclined to the horizon, and is by no means subject to faults even of the most trifling kind.

The whole Carboniferous period may be considered together in reference to the nature of animal and vegetable life at that time prevailing. Thus, although there are not wanting in the limestones, both of the Silurian and Devonian periods, some considerable number of coralline remains, there are no such accumulations hitherto known as to compare in extent or variety with those of the great bands of the mountain limestone. These indeed would seem to have been only paralleled by the somewhat similar formation now going on in the Southern Archipelago, and it seems by no means impossible that the general condition of the northern hemisphere, at the time we are considering, may have approximated to that of the southern hemisphere at the present day. In this way, many of the most singular differences observable in the animal inhabitants of the sea, and in the vegetables of the land, are best accounted for.

Besides the corals, there were many shells and other marine animals of low organization existing in these ancient seas, and they were peopled with a multitude of fishes, some of which approached in many important characters the true reptiles; and indeed we have distinct evidence of the introduction of reptiles during this period, though their remains are few, and belong to animals of small size. The passage from fishes into reptiles, indicated by the fishes of this period, is exceedingly interesting.

One of these, called, from its large proportions, compared with the other fishes of its period, *Megalichthys*, or the great fish, was even more remarkable for its robust proportions than its actual size. Its head, jaws, and teeth were especially formidable, the latter being sometimes as much as four inches long, and nearly two inches broad at the base—dimensions rarely attained even in the largest known reptiles. The body was covered with scales of corresponding magnitude (some of them five inches in diameter), and seems to have been well shaped for rapid motion through the water. The skeleton was bony and strong, the tail very powerful, and everything indicative of great strength, vigour, rapidity of motion, and eminently carnivorous habits.

Another very remarkable fish is called, from the wrinkled appearance on its scales and bony covering, "*Holoptychius.*" There is a nearly perfect specimen of this animal, measuring as much as thirty inches long without the tail, and the proportions are singularly massive. The head is small, but the unclothed jaws—covered with hard enamel instead of skin—are lined with a double row of teeth; the outer range thickly set, and fringing the enamelled edge of the mouth; the inner ones wider apart, and more than twenty times as large.

The scales covering the body of this animal singularly resemble those of reptiles, and might have served for the defensive armour of a crocodile five times as large as the fish.

But these were not the only fierce and powerful inhabitants of the sea during this period. No less than sixty species, belonging to various genera, but all of the shark tribe, and some of them of very large proportions, are known to have existed by the fossil remains discovered in the various limestone and other rocks, chiefly in England and Ireland.

This number is very much greater, and the fragments indicate a group of larger animals than we find characterizing the old red sandstone. They were also essentially different in many important respects from the reptilian fishes already described, and instead of having a secure casing of enamel, and impenetrable defensive armour, their skin was covered only at intervals with small and detached plates. There can be no question, from the analogy of recent animals allied to them, that these were the most powerful, the most rapid in their movements, and therefore the most important of all the inhabitants of the sea, and being probably, in most cases, the attackers, they did not need the contrivances for defence which are found in the heavier and less mobile, though more massive sauroid fishes.

Like the existing sharks, it is most probable that these fishes required to turn themselves round in the water, while in the act of seizing their prey, in consequence of the mouth being on the under side of the animal. For the purpose of being enabled to make this important movement with great rapidity and precision, they were, however, provided with a bony spine, connected, no doubt, with a fin, and inserted on the back. These spines, found in the Port Jackson shark, are not fastened to any bone, but are simply inserted in the flesh, and worked by strong muscles. They are very commonly found in a fossil state.

See, then, the change that had been effected towards the close of this period. The corals and encrinites remained, and the number of species had greatly increased, but those originally introduced had long since died out, and were succeeded by others resembling them, but not by any means identical. The trilobites had almost ceased to exist. The terebratula and other allied forms of bivalve shells had greatly multiplied in species, but the number of generic forms had diminished; and, on the other hand, the number of generic forms of the other mollusca had greatly increased. The cephalopods were still numerous. But the fishes are the most striking group. The minute but fierce and voracious species, which first marked the introduction of these animals, became succeeded by a clumsy and awkward race, heavy, slow, and only adapted to feed on the crustaceans and shell animals inhabiting the shallow water near shore; and these were defended by strong plates of armour, or delicate but perfect coats of mail. Then came the more predaceous, more powerful, and more rapid species (still, however, armed in the same manner), and then succeeded the sharks—the most remarkable of all for their locomotive powers, and their fierce and voracious habits. These were, however, associated with monstrous and enormously powerful species, well fitted to resist their attacks by the possession of defensive armour, like the plated mail of a large crocodile. There is no time known at which fishes so preponderated. There were, so far as we can tell, no groups ever introduced which exceeded these in the most remarkable points of development; and this, therefore, may well be called "the age of fishes."

But we have also indications of the land, and the vegetation with which it was

clothed. These are associated with beds of coal, the existence of which is almost, if not absolutely, confined to the geological period we are now considering, and which are met with in abundance in our own country, in North America, and also more rarely in various other parts of the world,—in Europe, Asia, and Australia.

Nothing is more certain than the true vegetable origin of coal. It has been determined by observing the general conditions under which the mineral occurs, the fossil remains associated with it, and by actual microscopic structure. Coal is altered and compressed vegetable matter, an accumulation of trees and of various other plants conveyed by some vast rivers, or living near a lake in ancient times. It is associated with many beds of sand and mud, which contain sometimes the impressions, sometimes the remains, of leaves and trunks of trees. The coal exists in many beds varying in thickness from a few inches to thirty or even fifty yards, and covering areas often amounting to many square miles, and sometimes to many thousand. But the thickness and extension give but a faint and imperfect notion of the quantity of vegetable matter belonging to the period; for a vast proportion must have died and undergone decomposition without forming coal, and the great compression the whole has since undergone has much diminished the thickness of any bed deposited.

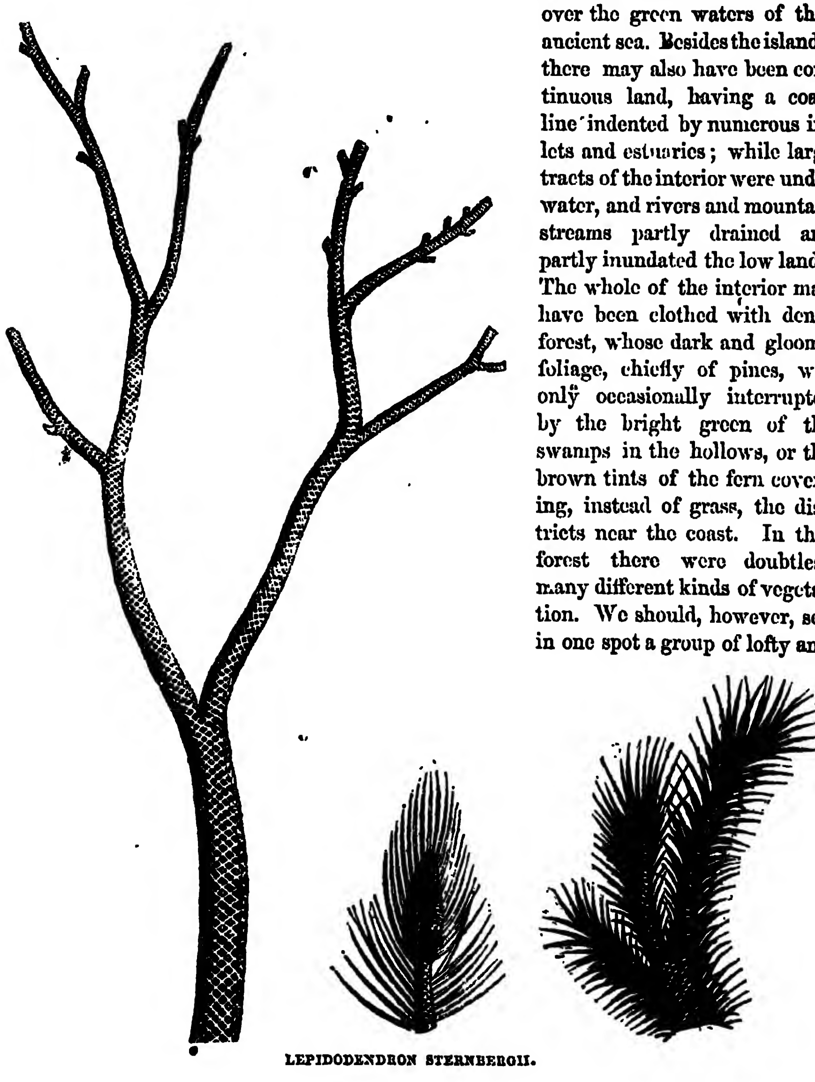
And the kind of trees—the nature of that vegetation which clothed the land in the northern hemisphere during the deposit of what was afterwards to become coal,—this is an inquiry of very great interest, and one which the fossils of the sandstones and slaty beds, amongst which the coal is stratified, serve to decide to a great extent, if not absolutely.

The first thing that strikes one, in looking at these fossils, is the singular prevalence of fern-leaves, and the total absence of such leaves and wood as characterizes the great majority of the forest trees of the present day in our latitudes. It is a very singular and interesting result of the investigations of naturalists on the subject of the distribution of plants upon the earth, that the region which most resembles this ancient condition of Europe includes very nearly our antipodes, being confined to parts of Australia and Van Diemen's Land, New Zealand, Norfolk Island, and other parts of the south temperate zone.

But although in these distant spots we do undoubtedly find a group of plants somewhat similar to those of the coal measures, and the dark ferns there take the place of our more cheerful grasses, growing in rank luxuriance into forest trees, and associated with palms as well as firs and pines, yet there is, after all, only a very general resemblance; nor is it likely that the ancient condition of the northern hemisphere greatly resembled the present Polynesia of the South Seas. One of the most remarkable characters of the coal fossils consists in the gigantic proportions of some groups of plants now uniformly small; but the resemblance, after all, is only distant, and we know but little yet of the true value of the differences observed.

There are, in our own coal, three well-marked generic forms of forest trees, and a gigantic reed, besides the numerous tree-ferns whose leaves or fronds abound in every coal district. Of these, one approached in some respects to the club mosses; one is exceedingly different from any existing tree, but was probably coniferous, and most like plants of the Zamia tribe; and the third resembles some of the singular pines of Norfolk Island. The coniferous tree, of which we know scarcely anything, was, it has been sometimes thought, connected with a singular but very abundant stem-like fossil, which has been supposed to form its root.

In order to realize, as far as possible, the ancient condition of our hemisphere, at the close of the carboniferous period, let the reader picture to himself a totally different arrangement of the land, which was at that time exposed to great changes of level, and which, after long descending, had been partly uplifted; so that a multitude of islands were studded over the green waters of that ancient sea. Besides the islands, there may also have been continuous land, having a coast line indented by numerous inlets and estuaries; while large tracts of the interior were under water, and rivers and mountain streams partly drained and partly inundated the low lands. The whole of the interior may have been clothed with dense forest, whose dark and gloomy foliage, chiefly of pines, was only occasionally interrupted by the bright green of the swamps in the hollows, or the brown tints of the fern covering, instead of grass, the districts near the coast. In this forest there were doubtless many different kinds of vegetation. We should, however, see in one spot a group of lofty and



LEPIDODENDRON STERNBERGII.

elegant trees (the so-called *Lepidodendron*), with a delicate tracery of fronds, clothing, in the utmost luxuriance, the slender and drooping branches which waved with every breath of wind. At a distance, in the more swampy places, the Calamites—the

arborescent reeds of this period—would be seen in clumps bearing aloft their singular branches and yet stranger leaf-like appendages, and standing stiffly up in a monotonous uniformity.

Not far off, and perhaps close to the moist places where vegetation was most rank, the *Sigillaria* would appear—a lofty tree, with a tapering and elegant trunk, with leaves only at the top of its perfectly bare and naked stem—a fluted column rising simply from the ground to a great height, and then crowned with a magnificent head of bright green foliage, like the recent Zamia. Perhaps this column rose from a circular and massive base, spreading out arms in every direction, and exhibiting in the roots those branches which were certainly absent from the stem.

TREE FERN.

But the tree ferns, and trees resembling the Norfolk Island pine, would probably be the most striking features in the landscape. They would occupy a prominent place, and their fallen leaves and trunks would perhaps render the forest almost impassable; but they would also be dotted at intervals over the distant plains and valleys, which were probably clothed with humbler plants of the same kind. These trees would exhibit rich crests of fronds, each crest hanging down gracefully over the trunk, and many feet in length, and the whole of the lofty forest trees would be girt round with innumerable creepers and parasitic plants climbing to the topmost branches, and enlivening, by the bright colours of their flowers, the dark and gloomy character of the great masses of vegetation.

Forests such as these are remarkable, even at the present day, for their death-like silence, and the almost total absence of land animals. A few birds and insects form the whole animal population, and no quadruped is found over extensive districts. Such was strikingly the case during the coal period. Vegetable life was infinitely abundant, but, with the exception of a scorpion, a few small freshwater shells, and a few crustaceans, we know of no terrestrial or lacustrine animals; and we find, therefore, that while the sea was then the habitation of fishes of considerable magnitude, and of high organization, on land there existed only vegetable life in abundance, and no highly organized animals appear to have been yet introduced.

After the deposit of the coal, a number of beds succeeded in most parts of the world, during a period when there seems to have been great and constantly repeated disturbance. The seas became less fitted for the larger fishes, and reptiles began to be introduced. The land became fitted for a somewhat different kind of vegetation, and the general physical features of the greater part of the existing land were then determined.

Permian Series.—The rocks immediately overlying the carboniferous series, and completing the Palæozoic epoch, are represented in England and western Europe by irony sandstones and magnesian limestones, with few fossils. These formed but an indistinct series, until identified with a large and interesting representative group in the ancient kingdom of Perm, in Russia, first described by Sir Roderick Murchison; but the whole are now generally recognised as the Permian system. Some peculiar mineral conditions in these rocks, and certain fossils, sufficiently separate the group from the carboniferous rocks, and at the same time fail to connect them with the oldest beds of the secondary period. They thus remain the uppermost and newest of the Palæozoic series, without indicating a passage to the overlying rocks.

PRODUCTUS HORRIDUS.

In England, the Permian rocks form a fringe round the northern crop of the coal measures, but disappear in the south and west. In France, they flank the Vosges mountains, and they have been traced in Germany and Belgium; but their chief development is, as has been said, in Russia. The mineral character varies but little, except that among the sands are occasionally thin bands of coal, and sometimes deposits highly cupriferous. The thickness varies, and in some parts of the Hartz mountains is as much as one thousand yards.

It was at one time a point of chief interest, in regard to these rocks, that the organic remains of reptiles were found in the magnesian limestones. Similar and other fragments have, however, recently been found in the true coal measures in various places; and there can now be no question that several genera of these animals belong to the coal period, and may perhaps be traced back to periods much more ancient. In addition to the reptiles, several peculiar and interesting remains of fishes have been found in the magnesian limestone, and numerous small corals and shells.

Recapitulation.—We have now traced the history of our globe, from the time when only a few marine worms crawled on the mud and sand of the newly made shores of a great ocean, through a period when there were other low forms of animal structure, and when marine vegetables or sea-weeds abounded. We have watched the appearance of the new-comers as they have presented themselves one after another, or in groups, and we have seen how different, and yet how like, they were, when compared with the present tenants of the sea. We have, in this way, obtained some notion, however slight, of the first doubtful and misty appearance of light and life in the morning of creation, as such appearance has by slow degrees become visible and appreciable to our senses. As time went on, however, the trilobites—the terebratulæ—the shell-fish of various kinds, one after another, become abundant and characteristic, and then died away, while the

nautilus and cuttle fish, or animals nearly allied to them, reigned undisputed lords of the ocean. At length, however, the reign of these animals also draws to a close, and fishes—creatures more highly organized—begin to appear. At first they are small and powerless, in comparison with the existing monsters of the deep; but they soon increased both in number and dimensions, and seem to have delighted in the troubled ocean, in which the great deposits of the old red sandstone were formed. For a long time the less perfect of the group seemed to prevail; but these were gradually displaced, and others more vigorous and more powerful succeeded them, and flourished till towards the close of the period.

While these changes were going on in the sea, the land also was attaining a more perfect adaptation, and becoming prepared for the residence of animals; but there seem to have been few, if any, of high organization, even among the Invertebrata.

Just at this point the first reptiles appeared, and we close the present portion of our history with a distinct intimation that the great work of nature was progressing—that the earth, long the habitation of one group of animated beings, was shortly to receive upon it another series possessed of higher organization and greater physical powers, and better fitted to the future conditions of existence.

SECONDARY EPOCH.

New Red Sandstone Series.—The transition from Palæozoic to Secondary rocks is by no means strongly marked by any mineral peculiarities, but the fossils found in them, even when the deposits are most evidently continuous, are considered to justify the separation. They are not only different in minute peculiarities, but indicate a total change in the chief conditions of existence, and probably the lapse of much time between the termination of the one and commencement of the other series. This time may have been largely occupied by movements of depression, as far as the chief European and American districts are concerned; but it is certainly remarkable that no distinct passage has yet been traced anywhere from the lower to the upper part of that series of sandstones which was first deposited during the Palæozoic period, and afterwards continued in a manner exactly similar into the Secondary period.

The new red sandstone, or, as it is often called, the Triassic series, includes, when fully developed, two groups of sand-rocks with occasional marls and much rock-salt, parted by a bed of limestone. The lower sandstone, called in Germany *Bunter-sandstein*, and by the French *grès bigarré*, is often of variegated colour, and contains numerous fossil plants and a few shells. It is tolerably uniform in its mineral character, and is very widely spread over the earth's surface. In England it appears as an irregular band, parallel to and near the coal measures, with which it is almost always unconformable. It occupies a large tract in the middle of our island, and spreads into Devonshire, North Wales, Lancashire, Yorkshire, and Cumberland. In France it is repeated in numerous localities, its chief extension being on the flanks of the Vosges; and in Germany it is very widely spread, especially in the Duchy of Baden and the Kingdom of Würtemberg. It ranges into Poland and Russia on the east, and into Italy on the south; and corresponding beds of the same age are known to exist in several of the United States of North America, and in various parts of the Andes.

A calcareous band, passing occasionally into a thick, well-defined fossiliferous limestone, frequently caps the *grès bigarré*, especially in Germany and some parts of France. It is called *muschelkalk* (or shell limestone), and in the Duchy of Baden attains a thickness of nearly a thousand feet, being equivalent to the greatest thickness of the under-

lying sandstones. The chief fossils of the new red sandstone series occur in this limestone band, which, however, is absent in England.

The upper new red sandstone, including in England numerous bands of marl and large deposits of salt, and elsewhere remarkable for marls of various colours (*marnes irisées* of France, and *keuper* of Germany), is widely spread in Worcestershire, Cheshire, and Devonshire. It is almost always nearly horizontal, and reposes unconformably on the coal measures or other Palæozoic rocks. Besides common salt, beds of gypsum, sometimes very thick and extensive, are found with the sands in England and elsewhere. The total thickness of this part of the series reaches in Germany to nearly 1,200 feet, and, though generally without fossils, many continental localities not only contain but are rich in organic remains, chiefly consisting of transported shells of marine animals.

The new red sandstone was long remarkable as the rock which contained the first distinct proofs of the existence of large air-breathing animals. At first the evidence of this was confined to foot-prints in the sand rock, supposed to have been made by birds and reptiles, but since then the actual bones of many reptiles have been found, and any doubts that may have existed on this subject are finally set at rest. The Labyrinthodon (see p. 93) affords remarkable proof of the general correctness of the first impressions of competent naturalists on this head, and there is little doubt that similar satisfactory proof will some day be obtained as to the existence of birds during the same period. Footmarks, at least, have been detected, which it is scarcely possible to refer to other animals. Besides the batrachian or frog-like labyrinthodon, of which there are indications of several very different varieties, the new red sandstone also contains remains of turtles and of other reptiles of curious form from South Africa.*

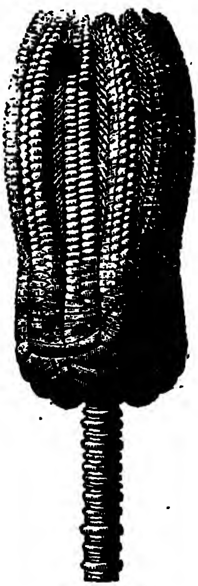
The total number of extinct genera, peculiar to the new red sandstone, is not great; but the variety is considerable. The plants differ decidedly, both from the Permian and carboniferous, manifestly approximating to the newer secondary and even recent types. The spongiform and coralline bodies are few (*Stellispongia*, see group of fossils, page 93), but the crinoidal family is well represented by a peculiar and abundant species (*Encrinites moniliformis*). The star-fishes are also peculiar (*Uraster*); and some of the bivalve and univalve shells (*Myophoria* and *Lottia*) are sufficiently remarkable, and easily recognised. The chambered shells (*Ceratites*) approach the ammonite, having departed completely from the older type of goniatite; while the fishes, of which the number of species is large, are also altogether distinct from any of those found in Permian rocks.

In these rocks of the new red sandstone or triassic period, we meet with distinct proofs of an extended coast line, and the actual remains of the flora and fauna of the adjacent land. In the coal measures, the plants whose vegetable fibre has since become coal are known by numerous fragments, and we have also these and freshwater animals of various kinds; but the analogies are obscure, and the flora is not yet made out to such an extent as to justify absolute conclusions. The land and freshwater animals also are confined at present to two or three small reptiles, the footprints of a

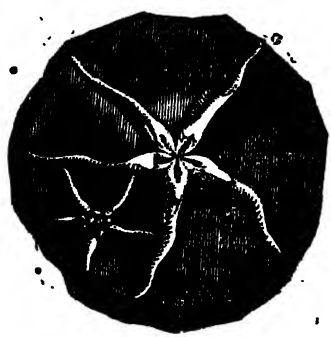
* It is now some years since unmistakable proof has been afforded of the existence of reptiles in the coal measures, and it has long been felt that the evidence of footprints and markings on sandstone was too strong to be questioned. The first actual bones were obtained from Germany, but since then others have been described from Nova Scotia, and latterly from the Glasgow coal-field. All these appear to be referred most fitly to the batrachian or frog-like reptiles, and they seem to have attained their highest development and largest size in the new red sandstone. Most of the carboniferous species are very small, although the one from Nova Scotia must have been nearly three feet long.—See "Quarterly Geological Journal," vol. ix. (1853), p. 68.

RESTORED FIGURE OF LABYRINTHODON, WITH MARKS OF FOOTPRINTS.

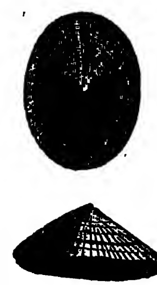
STELLISPONGIA VARIABILIS.



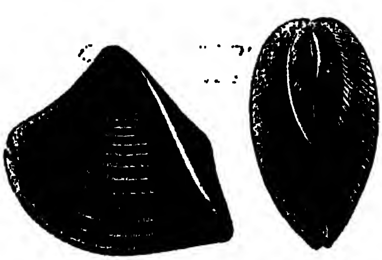
ENCRINITES MONILIFORMIS.



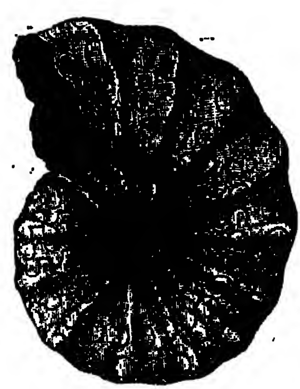
STAR-FISH.



TRIASSIC LIMPET.
(*Lottia lineata*).



MYOPHORIA LINEATA.



CERATITES NODOSUS.

supposed bird, one insect (a scorpion), a land-snail (genus *Pupa*), and a few cases of minute crustacea and river shells of doubtful character. In the new red sandstone the plants include true zamias, and approach those of the newest secondaries, while the reptiles must have been large, numerous, varied, and distinct, and the shells begin to assume known forms.

All these points are important, as marking the effect of time, and that gradual approximation towards existing nature, which becomes more manifest as we advance towards the recent period.

Compared with the older rocks, the new red sandstone is but slightly disturbed by faults, or elevated into hill and mountain. Being frequently soft, and containing marly beds, the sands yield an admirable soil, especially for herbage, in various parts of England. This sandy character is remarkably prevalent in most places where the rocks of the period have been recognised.

Liassic Series.—The passage from the new red sandstone upwards to the lias is seen in England on the north coast of Somersetshire, where a white micaceous sandstone overlies the new red sandstone. This bed often abounds with fossil remains of fishes, and in that case is blackened by the presence of a large quantity of animal bitumen. There is often only a few inches in thickness of this deposit; but it retains its character for a long distance through England. Over it are the calcareous flagstones, called "lower lias limestones," alternating with shales, and forming the lower division of the lias.

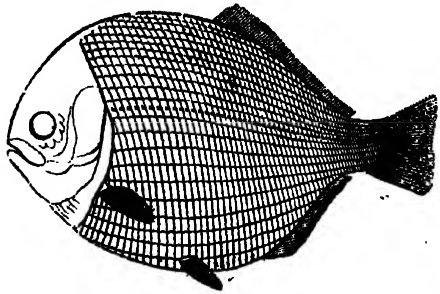
The lias itself must be regarded as the argillaceous basis of the whole Oolitic range, a large, varied, and important series of rocks as recognised in England, and on the Continent generally called Jurassic, because chiefly developed in the mountains of the Jura, between France and Switzerland. Taken as a combined group, this series involves a total thickness of at least five thousand feet, of which the lias forms a considerable part, and consists chiefly of alternations of limestone and clay, with but few deposits of sand, and those not of great thickness. These deposits together mark a period during which a good deal of land must have existed, and when there must also have been a good deal of alternation of level. Numerous fossils are found in all parts, varying according to the circumstances of deposit, and affected by the climate, depth of water, and the nature of the disturbances of the district.

These beds are well represented throughout Central Europe, and are repeated, though less extensively, in Asia, and in North and South America. Our own island is especially rich in indications of all kinds leading to a knowledge of the conditions of the earth during this period. The general arrangement and distribution of the fossils, as far as it has been determined, will appear in the following description; but it will of course be impossible to give more than a very brief account.

The *lower lias shale*, already referred to as the base of the argillaceous portion of the lias, is well seen at Lyme Regis, in Dorsetshire, where it abounds with characteristic fossils, among which are many of those remarkable reptilian remains for which the oolitic rocks are so well known. Among the shells there is one especially characteristic (*Gryphæa arcuata*—see group of fossils, page 95), which gives a name to some of the contemporaneous beds on the Continent. This shell closely resembles an oyster. The *Ammonites bisulcatus* is also a species met with chiefly in the lower lias; but the shells of this genus are widely distributed throughout all the middle secondary rocks.

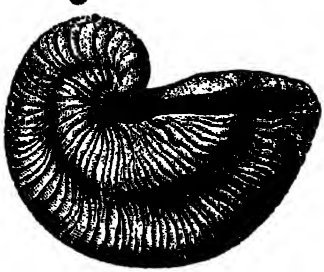
The peculiar appearance of the middle lias, as a blue argillaceous limestone, often

GROUP OF LIASSIC FOSSILS.

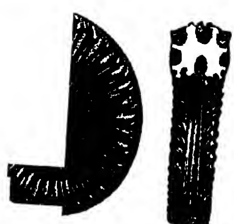


TETRAGONOLEPIS (*Restored Form*).

CIDARIS CORONATA.



GRYPHÆA ARCUATA.



AMMONITES BISULCATUS.

BELEMNITES.

PECTEN LUGDUNENSIS.

SPIRIFER WALCOTI.

PLESIOSAURUS DOLICHODEIRUS.

striped (whence it is supposed the name *lias* or *layers* is derived), and abounding with fossils, is well shown in Gloucestershire and Leicestershire. Near Cheltenham there is also a whitish-gray variety called *marlstone*, sometimes sandy and sometimes more calcareous. It contains, among other fossils, numerous remains of wood, thick masses of encrinital remains, chiefly of a genus (*Pentacrinus*) peculiar to these beds, and of wide extent, some sea eggs (*Cidaris*), many bivalve shells, as well of forms resembling existing species (*Pecten*), as those more common in the old rocks, and now dying out (*Spirifer*). There are also vast numbers of ammonites and belemnites, the latter genus of chambered shells then appearing for the first time, while the ammonites are also unknown even in the new red sandstone, except in the modified form of ceratites—connecting the more typical forms with the goniatites of the mountain limestone and the clymenia of the Devonian rocks.

The fishes and reptiles of the lias range throughout the whole of the subdivisions of the deposit, and even extend, either by identical or closely-allied species, into the upper rocks of the middle secondary group. They may therefore be regarded as having belonged to the period generally, and cannot be properly referred to as peculiar to any part.

The upper lias—often worked for alum at Whitby, on the Yorkshire coast, and hence called *alum shale*—is of considerable thickness, and contains, amongst its deposits, a thick band of vegetable matter, in which are found lumps of jet—a peculiar mineral, consisting chiefly of carbon and hydrogen, and no doubt of organic origin. This part of the lias also abounds with the fossils already alluded to as characteristic of the whole series. The remains of fishes and reptiles are often so nearly perfect that it has been found possible to reconstruct, from the skeletons buried in the rock, the complete form of the animal, and thus bring again into view those organic forms which have for myriads of years been extinct. The fish and reptile, in the group of fossils annexed (see page 95), are instances of the mode in which this has been done, merely by applying to the fossils a competent knowledge of comparative anatomy.

The application of this knowledge, combined with a great amount of constructive talent, has produced, in the grounds of the Crystal Palace at Sydenham, a series of groups of restored animals, combining the interest of romance with the strictest regard to actual truth of representation. It is impossible that any one can form an adequate idea of the effect without seeing and studying these singular and striking restorations, which include almost all those species in which there is sufficient evidence of form, and sufficient difference from known animals, to justify the trial.

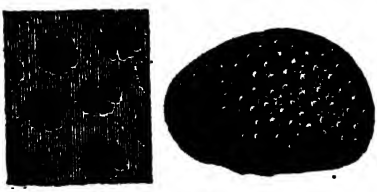
Oolitic Series.—The oolitic series, as exhibited in English geology, consists, as has been already said, of alternating bands of limestones and clays, with very little intervening sandstone. The limestones almost always present a singular appearance, being made up of very small globules not unlike the roe of a fish, whence the name *roe-stone*, locally given, and translated into *oolite*, as a scientific term. These small particles are found, on careful examination under a microscope, to be concentrically arranged, with some minute organic particle in the centre; and they are assumed to present a peculiar kind of segregation, not unlike crystalline action. The limestones, although usually of this kind, differ considerably in colour, hardness, fossil contents, and even in the extent to which they have undergone crystalline action. They are accompanied by clays which contain some peculiar minerals (as fuller's-earth), but which, for the most part, offer nothing remarkable.

The following is the grouping of these rocks in detail:–

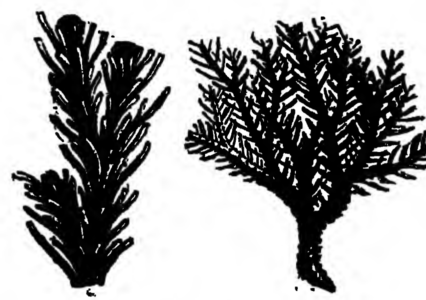
UPPER OOLITES, . .	Portland stone. Portland sand. Kimmeridge clay.
MIDDLE OOLITES, . .	Upper calc grit. Coral rag. Lower calc grit. Oxford clay. Kelloway's rock.
LOWER OOLITES, . .	Cornbrash. Forest marble. Great oolite. Bradford clay. Stonesfield slate. Fuller's earth. Inferior oolite.

The *inferior oolite*, well illustrated at Dundry Hill, Bridport, and Leckhampton, in the west of England, is also very widely distributed in France and elsewhere on the continent of Europe. It includes some building stones greatly used, and some iron ores not without value. In the west of England the available portion is a freestone forty or fifty feet thick, which is separated from the great oolite (so called as containing the principal workable beds of stone) by a series of marly beds, clays, and calcareous flags. Of these, the clays often consist of what is called *Fuller's earth*—a variety

GROUP OF LOWER OOLITE FOSSILS.



OOLITIC CORAL.



CORALLINE.

AMMONITES BULLATUS.

JAW OF OOLITIC OPOSSUM.

DYSASTER (A SEA URCHIN FROM DUNDRY).

containing a large percentage of water, and valuable, from its highly absorbent qualities, in the manufacture of cloth. The flagstones, under the name of *Stonesfield slate*, are

known to be singularly rich in some kinds of fossil remains; among the most remarkable of which are the jaws of one or two didelphine animals (opossums) that have been found there, whilst no other example has yet been met with of quadrupedal remains in secondary rocks of this or any newer date. The appearance of these little fossils will be seen from the figure annexed. With them are associated numerous vegetable remains, consisting of leaves and fruits, some remains of insects and crustaceans, and many fragments of fishes and other marine animals. There are also bones and teeth, often of gigantic proportions, referred to land reptiles, including both vegetable feeders and carnivores.

The great oolite contains the celebrated Bath-stone, and other almost equally well-known and valuable building material. It abounds also with fossils, chiefly univalve and bivalve shells. Minchinhampton is a particularly rich locality; and here the corals, sea-eggs, ammonites, belemnites, and terebratulæ, which are characteristic, are found in abundance. Some of the former have already been figured.

The *Bradford clay*, sometimes alternating with and sometimes replacing the great oolite, contains a bed on which are found vast numbers of fragments, and some nearly complete remains, of a singular crinoidal animal, called the apiocrinite, or pear encrinite. It closely resembled a species figured on the following page, but was shorter and perhaps rather less elegant in form. The whole of this lower series is represented in Yorkshire by ironstone nodules, and hard blue fossiliferous limestones.

The *cornbrash* and *forest marble*, covering the great oolite, consist of limestones in various conditions, often decomposing, but sometimes semi-crystalline.

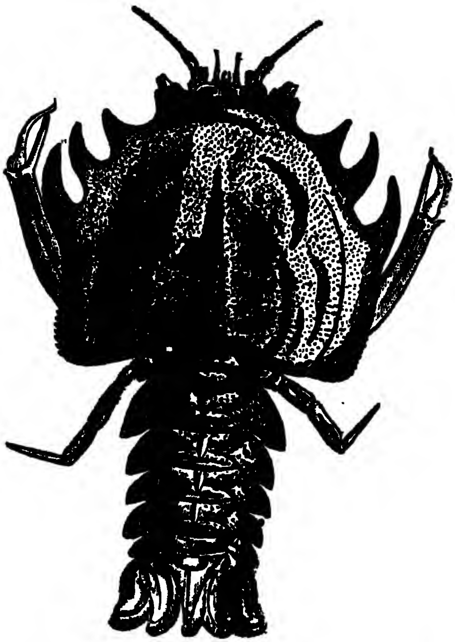
In France, the fine and valuable limestones of Caen, in Normandy, belong to this lower part of the oolitic series, and contain similar fossils; and in Germany corresponding beds are known to exist. In some parts, both in our own country and elsewhere, the lower oolites contain very important deposits of coal, which are represented in Yorkshire (England), and extensively worked near Richmond, Virginia, U.S. The coal fields of India appear to include some beds of oolitic age.

The middle oolite is almost as varied and subdivided as the lower. The *Kellaway rock*, which has been long known, forms the base of the deposit, and, though paltry in England, assumes importance from its continental development. It is a kind of calcareous sandstone, abounding in organic remains, of which the *Ostrea marshii*, *Gryphæa dilatata*, and *Ammonites Jason*, are characteristic. This bed is not only widely distributed in France and Germany, but is also well represented in Cutch, near Bombay.

The *Oxford clay*, a stiff pale blue argillaceous bed, sometimes attaining in England a thickness of 500 feet, is the principal member of the middle oolitic series in this country. It occurs on the south coast at Weymouth, and again in the middle and east of England, in the great fen district of Cambridgeshire, Huntingdonshire, and Lincolnshire. It ranges through France into Switzerland and Germany, and is widely distributed in Russia, reaching to the shores of the Black Sea and forming the southern extremity of the Crimea. It has been found also in Asia Minor.

Among the fossils of this deposit are some highly interesting crustaceans, and many chambered and other shells. The fishes and reptiles of other parts of the oolites extend here, and are not rare; but the organic remains are often filled with iron pyrites, which, decomposing readily, soon destroy all trace of the form.

There are often calcareous beds intervening between the Oxford clay and another very similar and also thick bed belonging to the upper oolites. The most persistent and

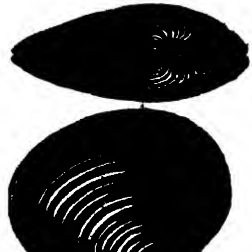


ERYON ARCTIFORMIS.

AMMONITES JASON.

OSTREA MARSHII.

GRYPHÆA DILATATA.



ASTARTE ELEGANS.

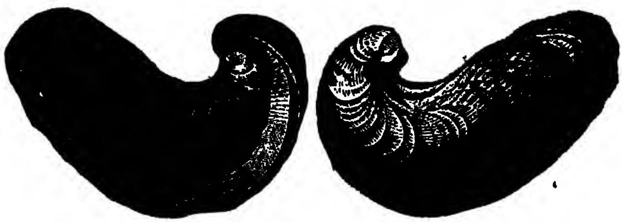
APIOCRINUS.

distinct of these is a coral bank of no great thickness, containing often a good many shells and some encrinites; of the latter, the species figured on the preceding page is sufficiently perfect to give an accurate idea of the peculiarities of the genus of which it is a member. The corals differ but little from many existing species.

GROUP OF UPPER OOLITE FOSSILS.

CYCADEOIDEA.

TRIGONIA GIBBOSA.



GRYPHÆA VIRGULA.

SPINE OF CIDARIS GLANDIFORM.

In the absence of the coral rag and other calcareous members of the middle oolites, the Kimmeridge clay, the lower part of the upper oolitic series, reposes on the Oxford clay, producing in that case the fen district of the east of England. It is characterized by the *Gryphæa virgula*, which is in some districts (chiefly in France) very abundant, and spreads over a large tract of country in western Europe, where the clay and limestones of the same age are met with.

Numerous reptiles, of which turtles and alligators were the most common, seem to have inhabited the seas and muddy shores; but these differ but little from those already alluded to, most of which were common to the whole secondary period. Like those of the Oxford clay, the fossils from the Kimmeridge beds are rarely to be preserved for any considerable time.

The Portland beds, consisting chiefly of hard limestones, contain some beds of admirable freestone; and these alternate with thin bands of a brown substance resembling lignite, and called locally the *dirt bed*. This is in reality an ancient soil, on which grew numerous trees, some allied to the Cycas and Zamia (see *Cycadeoidea*, figured above), and others more like trees now living in similar latitudes. In the Portland limestones, which are very limited in their range in the British Islands, there are numerous fish and reptilian remains, and a large number of shells.

The north of Bavaria exhibits a large development of oolitic rocks, chiefly of the

later middle and newer period, amongst which are the remarkable and valuable lithographic limestones of Soluhofen, rich in fossils of various kinds. The fossil cray-fish (*Eryon arctiformis*) (see p. 99) is from this deposit, and numerous other remains in singular perfection have been obtained.

Wealden Series.—The close of the oolitic period does not seem to have been marked in England by any violent disturbance, nor, on the other hand, do the rocks pass insensibly into those of the cretaceous series. There is a considerable group intercalated, manifestly formed under fresh water, and thus marking an interval, which, in spite of careful observation on the Continent, where the intervening beds are absent, has not been fully accounted for. It is clear that a large tract must have been previously elevated into a position sufficiently near the ground now occupied by the weald, to have admitted of the accumulation of those large fresh-water deposits; and we may fairly assume that there certainly was a large extent of land, though it may not have approached in magnitude many existing islands.

The wealden deposits consist of the Purbeck beds (immediately overlying the Portland rock), the Hastings sand, and the weald clay. The latter is in its turn covered

GROUP OF WEALDEN FOSSILS.

TEETH OF IGUANODON.

CYTHERE AURICULATA.

UNIO WALDENSIS.

by the beds of lower greensand, finely developed in the south-east of England, though far more largely in various parts of Continental Europe.

The Purbeck beds, as shown in the islands of Portland and Purbeck, and repeated in other parts of the south-east of England, consist of coarsely fissile limestone and

slaty clays, of which there is a singularly numerous alternation. Some portions of the series form a kind of shelly marble, formerly much used in cathedral work for small columns. Most of the beds abound with fossils, chiefly of fresh-water shells, and numerous fragments of turtles and some reptilian remains prove that we are examining in these beds accumulations made in the immediate vicinity of land. The total thickness of these deposits exceeds 125 feet; but they are confined to a small area.

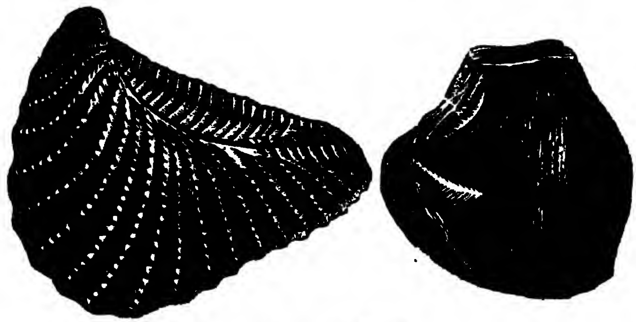
Overlying the Purbeck beds is a comparatively large series of sandy deposits, which forms the great thickness of the wealden series. The Hastings sand is the name commonly given to these beds by English geologists, and they have also been called Tilgate beds. They are well shown as soft sands in the Hastings cliffs, and in the caverns cut in the rock close by; and as hard beds used for building stone, they are quarried in Tilgate Forest and Tunbridge Wells. This part of the weald occupies a large space between the chalk hills of the north and south Downs. The Tilgate beds have yielded numerous fragments of some of the most remarkable reptilian fossils yet discovered. The *iguanodon*, a land lizard, whose teeth (see page 101) and jaws indicate an animal of strictly herbivorous habits, but exceeding in size the largest elephant, was accompanied by the equally gigantic and carnivorous *megalosaurus*, and by the two yet more curious reptiles, the *hylæosaurus* and *pterodactyl.*

To form any idea of these, the reader must make acquaintance with the ancient world, as represented in the grounds of the Crystal Palace, and will there find restorations of the animals sufficiently perfect to illustrate this reptilian epoch.

The weald clay, a band of argillaceous rock with some poor limestones, containing fresh-water shells and other fossils terminates the wealden series. The limestone, known as Sussex or Petworth marble, resembles the Purbeck marble, but is rarely more than a foot in thickness, and is only partially used for economic purposes. The clay extends round the whole wealden district, but possesses few features of interest.

Lower Greensand Series.—Except in the Bas Boulonnais, a small tract in France exactly opposite our wealden, with which it corresponds in many respects, the beds of the weald are not repeated in Europe. Nor is it probable that there should be any such repetition. The contemporaneous beds, of which we have many, were probably not deposited like these in a river estuary, near a large tract of land; and even if they were accumulated near land, were so under very different circumstances. Thus parts of extensive deposits in Germany and elsewhere have been assumed to represent the wealden in point of date, but have no resemblance whatever in mineral character, and little, if any, in fossil contents. They merely appear to be intercalated between those beds whose fossils prove them to be contemporaneous with the upper oolites and beds of the age of our greensands overlying the wealden. The marine series, connecting the oolitic and cretaceous systems, are for the most part either altogether absent or very imperfectly represented in the British Islands, as a natural consequence of the existence of large tracts of adjacent land at this period.

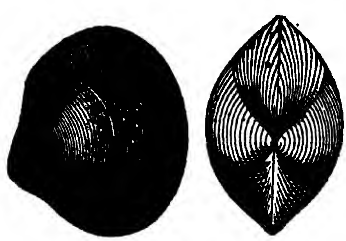
Around the town of Neufchâtel, in Switzerland, and over a large tract in France, are deposited those beds which, from the former locality (Latin, *Neocomum*), are called *neocomian*. They exhibit in some places a thickness of as much as 10,000 feet, and extend not merely in the countries already mentioned, but along the shores of the Mediterranean, and throughout Germany. The prevailing rock is sandstone, which in many places contains grains of silicate of iron, giving a green colour. These are sometimes replaced by the peroxide of iron communicating a deep red tint; and not unfre-



TRIGONIA ALÆFORMIS.

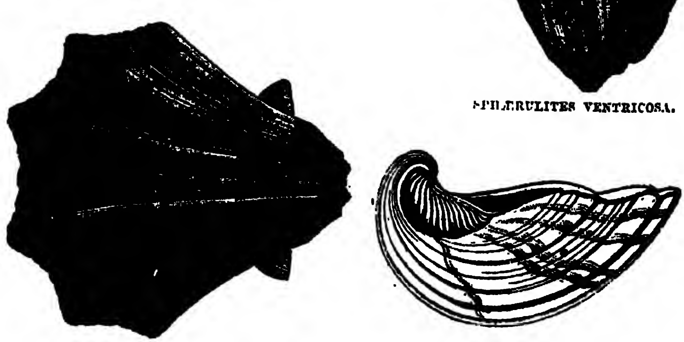
TEREBRATULA SULCATA.

ICHTHYODORULITE.



CARDIUM PEREGRINUM.

SPHÆRULITES VENTRICOSA.



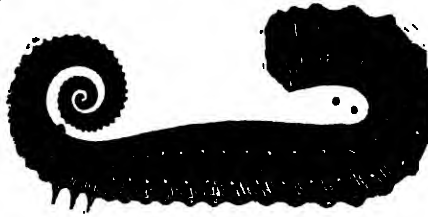
PECTEN QUADRICOSTATUS.

quently on the Continent the percentage of metallic iron is sufficient to justify the use of some bands as iron ore. Elsewhere, however, the iron is altogether absent, and the rock white and even chalky in its texture, while in the Alps it is replaced by blackish marly limestones, and chloritic limestones. Owing to the prevalence of the green particles in rocks of this age in England, and also in other sandstones a little higher in geological position, the name *lower and upper greensands* have been applied to the two series. The enormously greater development of the former, however, and its wide distribution, render it desirable to change a nomenclature founded on imperfect observation. The name *neocomian* has thus been usually adopted of late years in speaking of this lower member of the cretaceous series. The neocomian fossils include a large number of species, showing a gradual change from oolitic types. Besides many spongiform and coralline bodies, and a few radiata, there are numerous shells and crustacean remains. The former include, amongst bivalves, several pectens, cardiums, and allied shells, and numerous terebratulæ (see page 103). There are also some singular shells belonging to a tribe now extinct (*Sphærulites*), which first appear in the cretaceous rocks, and, although rare in these lower beds, were afterwards more common. Several ammonites and the remains of fishes, amongst which may be mentioned the defensive fin of one of the shark tribe (see figure of *Ichthyodorulite*, p. 103), are also found, besides numerous remains of reptiles, some of gigantic proportions, and generally of marine habits. All these mark the close resemblance of the conditions of the sea with that which obtained during the oolitic and even the liassic period. Numerous chambered shells prove the existence of a wide expanse of shore and shallow sea in some districts; while elsewhere the great thickness of the deposits, the small number of fossils and their nature, render it probable that the sea was extremely deep.

The bed, called on the Yorkshire coast *Speeton clay*, and elsewhere forming the uppermost capping of the lower cretaceous series, is sufficiently distinct from the great mass of neocomian deposits to justify a separate description. It has sometimes been regarded as belonging to the middle part of the cretaceous series, and usually consists of a plastic clay, often foliated and decomposing on exposure to the air. In England it is of no great thickness, but contemporaneous beds in the Alps have a thickness of upwards of 600 feet. It is widely spread, and has even been traced so far as at Port Famine, in the Straits of Magellan, whence fossils have been brought which are referred to this period. The *Ancyloceras*, a singular modification of the ammonite, and the *Thetis*, a bivalve shell (see page 105), are regarded as characteristic, and are found in abundance in certain localities.

Gault.—A very well marked band of blue clay extends everywhere in England, between the uppermost beds of the lower green sand, or neocomian series, and the so-called upper greensand. It is known locally as the *gault*, and is often used as a building clay. Elsewhere it is combined with pale green, or whitish sands and sandstones, but is tolerably regular as a transition bed between the uppermost neocomian and chalk deposits. Its greatest thickness hardly exceeds one hundred and fifty feet. It was probably deposited in a shallow sea, near shore. The *Turrilite*, an ammonite with an elongated spire, is often found in the gault; and corallines, sea-urchins, and terebratulæ (see page 105) are also abundant.

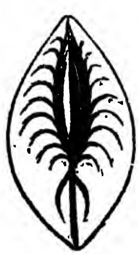
Upper Greensand.—Somewhat higher in the series occurs the *upper greensand* of English geologists, well exhibited in the Blackdown Hills in Devonshire. This locality has long been remarkable as abounding in fossils, many of which are almost confined to the locality. They are remarkably well preserved, and very varied in their

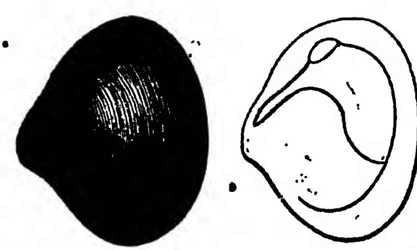


ANCYLOCERAS.

TURRILITES.

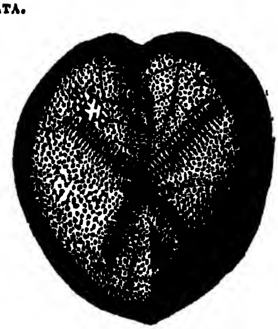
CORALLINE.





THETIS LÆVIGATA.

TEREBRATULA DIGONA.



SPATANGUS COR-ANGUINUM.

nature. They include sponges, sea-eggs, numerous minute foraminifera, bivalve shells of various kinds, univalve shells, ammonites and belemnites, turrilites and hamites, fragments of fishes, and reptilian remains. A group of some of the more notable and characteristic will be found annexed.

The Blackdown upper greensand is represented on the Continent by several deposits in France, by parts of the Quadersandstein of German geologists, the upper Carpathian sandstone, and by several not unimportant deposits in Portugal, near Lisbon, and in Spain (at Oviedo). The rest of the upper greensand of England (the firestone of Mantell) is of the same date. In Spain the thickness of beds of this period is as much as fifteen hundred feet, according to the estimate of M. de Verneuil.

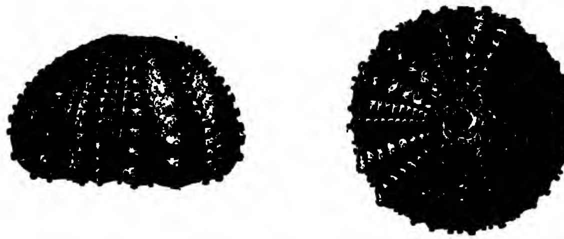
Extensive beds of lignite have been found in some of the deposits of this period. There has evidently been a considerable quantity of wood and other vegetable matter floated down with mud, and more or less injured by exposure. The beds contain amber or fossil resin, and much of the wood is pierced by marine worms, and covered by oysters.

Upper Cretaceous Series.—The uppermost member of the whole secondary series reposes directly upon thin beds of marly impure sand, and white or gray marl usually succeeds the upper greensand, passing upwards into white chalk. In England this part of the upper division of the cretaceous system is represented by the chalk marl and the lower chalk without flints, but elsewhere it forms a distinct deposit containing numerous remains of that very remarkable fossil family, the *Rudistes*, already alluded to in speaking of the lower greensand sphærulite. The chalk marl is so far developed in the Touraine district of France, that it has been received among French geologists as the Turonian system. It is also seen in Spain, where, near Oviedo, the thickness is stated to amount to six hundred feet. Besides the Rudists, of which the *hippurite* and *crania* (see page 109) are good examples, there are numerous chambered shells, including some ammonites of gigantic proportions. The small *trigonia* (see page 109) is characteristic of this part of the chalk.

Overlying the chalk without flints, which is generally somewhat impure and argillaceous, we have the pure white chalk of England, marked by flint bands. This bed is too well known, both in its mineral character and distribution, to require any description; and it extends not only through our own island, from Dover and Beachy Head to the coast of Yorkshire, but crosses the German Ocean to Denmark and the British Channel to Normandy, whence the beds are continued through a great part of Europe, meeting at last on the frontier of Asia. Rocks of the same age, but of different mineral character, are found in North America in various localities, and extend into Central and South America. The total thickness of the white chalk reaches, in some places, to one thousand feet.

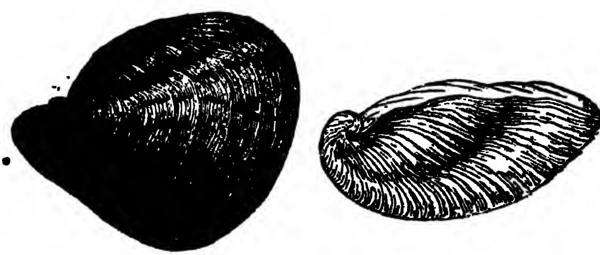
The fossils of the white chalk are all marine; but they are abundant and varied, including numerous sponges and foraminiferous shells, sea eggs and sea urchins, bivalve shells (of which *Trigonia* and *Plagiostoma* are both common and characteristic), and univalve shells, also remarkable (see page 109). The chambered shells include a variety of ammonites, and allied forms expanded in singular shapes; and one genus (*Belemnites*), very common, indeed, among all the secondary rocks, from the lias upwards, appears here, together with many other cephalopodous shells for the last time. A species of nautilus (see page 109), found in the newest chalk deposits of Denmark, and a large marine reptile, the mesosaurus, of which remains have been chiefly found near Maestricht, but also in our own chalk, belong to the newest beds of this series.

CARDIUM HILLANUM.



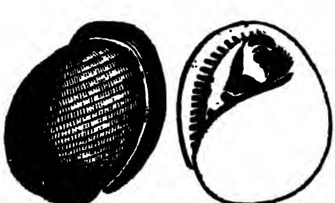
GONIOPYGUS MAJOR.

SIPHONIA PYRIFORM.

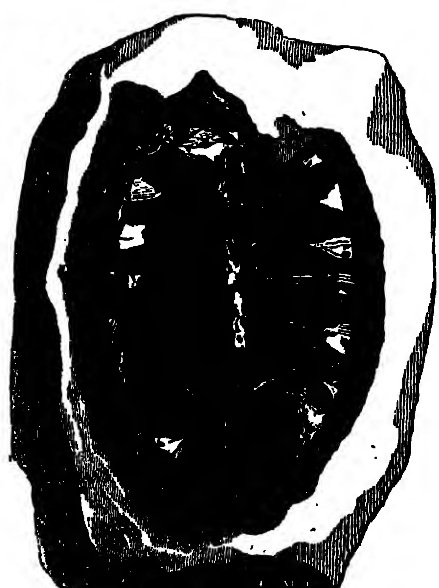


GRYPHÆA COLUMBA.

FORAMINIFEROUS SHELL.



AVELLANA CASSIS.



CHELONIA BENSTEDI.

Remains of fishes, and of several of the large reptilian animals, nearly resembling those of the oolites, are found in the chalk; but, in addition to the former, there are a vast number of fishes introduced for the first time. The whole deposit of the chalk seems to have taken place in deep water, when there was a remarkable abundance of calcareous mud.

The chalk has always been regarded as the highest deposit of the secondary series, and is certainly the last formed of those rocks whose varied organic contents have enabled naturalists to deduce the exact conditions of the particular districts during the time when the deposit was progressing. Strictly speaking also, there are no beds hitherto found lying above the chalk, and showing that kind of transition which has been recognised in other cases of older rocks where a succession exists. But although this is the case, there are extensive and thick deposits, containing fossils, either corals or foraminiferous shells, which have been supposed to represent the period that elapsed after the completion of the cretaceous rocks, and before the overlying tertiaries were commenced. Such rocks occur in the Mediterranean. The *Scaglia* and *Alberese* of Italian geologists would seem to be strictly representative of parts of the cretaceous series; but the *Macigno* is of doubtful age. Some of these rocks have been originally deposited in very deep open water, with a comparative paucity of fishes and the absence of littoral species both of fishes and molluscs.

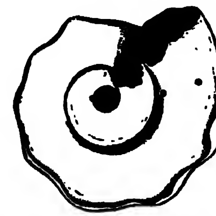
Recapitulation.—Having now considered very briefly the principal deposits that in England and on the continent of Europe succeeded each other in regular order, during the whole secondary period, it may be well to group together the principal facts, as far as possible, and present the reader with a kind of general summary of the conditions of existence in that part of the world at present occupied by our island. To do this, we shall have to appeal a little to the imagination, in order that the reader may picture to himself its possible appearance, could those strange scenes, once enacted here, be recalled, or could a reasonable being, like man, have been present, as a witness, at the commencement of the deposit of the secondary rocks. At this time the earth had indeed long existed as the habitation of living beings; but we are here first made acquainted with the actual condition of the land and with the animals upon it and near it.

We may first imagine a wide, low, sandy district, by the sea side; the limestone hills and cliffs now rising boldly on the shores of the Avon and in Derbyshire and Yorkshire had then been recently elevated, and formed part of the land; and on the sandy banks, just above the ordinary level of high water, wandered ancient and singular animals of which a few fragments only have been handed down for our observation. Amongst these we may safely enumerate one little lizard, with a bird-like beak and bird's feet, many turtles and tortoises, and a multitude of birds—some larger than an ostrich, others as small as our smallest waders. In South Africa there were also reptiles of considerable size and in great variety, whose two tusks, in an otherwise unarmed jaw, strikingly distinguish them from any of their contemporaries.

But strangest of all among these would appear the gigantic labyrinthodon, and its smaller congeners. One of these animals, nearly as large as a rhinoceros, comes leisurely pacing over the sands, leaving behind it the vast imprint of its hind feet, contrasting oddly with the little toes of the fore extremities. One of the smaller of these animals, provided with a long and thick tail, recognised by the mark with which it has indented the soft mud it passed over, may have sought, perhaps successfully, to escape from the attack of its larger but slower enemy. Both would approach the water as the best field of their exertions, and we should soon have no vestiges of their having

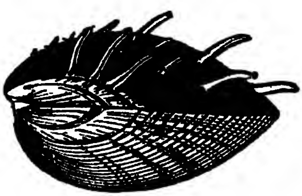
CHALK SPONGE.

GALERITES ALTOGALERUS.



PHORUS CANALICULATUS.

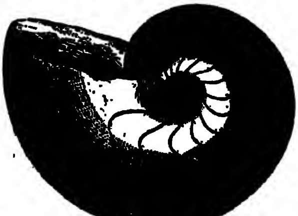
BELEMNITES MUCRONATUS.



PLAGIOSTOMA SPINOSA.

TRIGONIA SCABRA.

HIPPURITES TOUCASIANA.

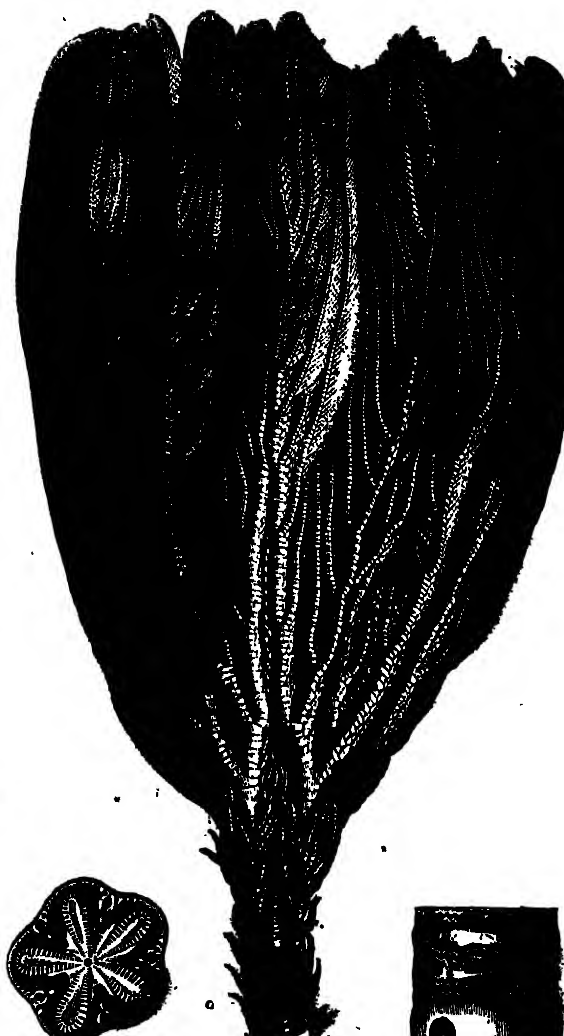


NAUTILUS DANICUS.

PLEUROTOMARIA SANTONENSIS.

been present, beyond the imprints of their feet, made on the rippled surface of the tenacious mud, as they passed along.

Of the plants of the new red sandstone period, there is quite sufficient information to enable us to assume with confidence that they differed considerably from those of the coal period, but that still fern vegetation was abundant. Calamites also remained, though in a modified form. We know of no insects or quadrupeds, although they probably existed.



PENTACRINUS FASCICULOSUS.

The sands and marls deposited and sunk down to form a sea bottom, and the clay of the lias being in course of deposition, we have a new order of things, and a very different arrangement, in consequence of the prevalence of argillaceous mud, instead of sands, in the deposits. A wide expanse of gulf, of no great depth, was being filled with material perhaps brought down by one or more large rivers. The climate was warm, the vegetation on the shores rank and luxuriant. Trunks of trees, constantly carried away by alterations in the mouths and deltas of the streams, were continually drifted off into the gulf; and attached to them would be found large clusters of *Pentacrinites*, collected like bunches of barnacles on the drift wood. These singular extinct animals, the representatives, perhaps, of others now equally abundant, but of different appearance, were provided with means of secreting stony portions, which, when fitted together, formed a moveable stone column, thickly fringed with branches similarly provided, and terminated by a cap made also of stony plates fitting together, forming a stomach partly

closed by a proboscis, also defended. With innumerable arms, widely extended in a complicated fringe, this mass of living stone seems to have served as one of the scavengers of the deep, removing and assimilating the half-decomposed animal matter, that would otherwise have proved injurious to the inhabitants of the surrounding land.

While the pentacrinite thus floated about, conveyed by the drift wood, the oysters of that time were planting themselves at intervals; and the terebratulæ and spirifers, assisted by numerous crabs and other crustacean animals, appear to have found ample food in these seas swarming with life. But of all the invertebrata, with the exception perhaps of that singular tribe just described, none would be more prominent or actively employed than the inhabitants of those many-chambered shells that have already been several times alluded to as highly characteristic of the secondary period. Of these animals the *ammonite* and the *nautilus* were then abundant; and the variety of forms presented by the former genus is only less remarkable than the number of the remains of individuals which are found throughout the lias collected in particular localities. These creatures, partly inclosed in their shells, floating and swimming at various depths, and accompanied by the yet more powerful and rapacious *belemnite*, rendered the mollusca a very important group at the period in question.

The shores and shallows, and probably also the open sea to some distance from land, were at this time peopled by multitudes of moderate-sized fishes, varying from a few inches to three or four feet in length, living chiefly on the crabs, lobsters, and shell-fish of various kinds, which we have reason to know were extremely abundant. These fishes had a hard, solid pavement of teeth covering the palate, to crush the shells and stony cases of their prey. They were themselves also inclosed in a strong enamelled armour, and perhaps fed not only on offal, and on the less powerful invertebrata, but on each other. Further out at sea were tribes of sharks, of various sizes and different species, but all voracious and predaceous in the highest degree, and some of them attaining very large dimensions. No fishes, such as are now most common about our own or the neighbouring shores, then existed on the earth.

RESTORATION OF VARIOUS LIASSIC ANIMALS.

But the fishes, although represented by a powerful and important group, had ceased to be the lords of creation in the lias seas. From the banks and shoals, crowded with myriads of living beings, the great *Plesiosaurus*, with its long neck and small wedge-

shaped head lifted high in the air, might be seen paddling rapidly along, plunging into the deep water, and there, like the fabled sea-serpent, darting through the waves, and occasionally striking with unerring aim at its prey, consisting probably of fishes, turtles, and the larger cuttle-fish and other cephalopoda, which were so plentiful.

Next, let us picture to ourselves some of the deeper abysses of the ocean, and seek for the powerful and rapacious monsters whose abundant remains prove how important was the part they then played. Prowling about far below the surface, but with an eye glaring upwards, like a large globe of fire, the ichthyosaurus may be supposed to distinguish the work going on above, and watch the plesiosaur in its search after prey. Suddenly, and with one stroke of its powerful fore-paddles, and the powerful action of its huge tail-fin, it rises with the velocity of lightning to the surface; its vast mouth, lined with formidable rows of teeth, opens wide to the full extent; it overtakes the object of its attack, and with a motion quicker than thought the jaws close, and perhaps some plesiosaur falls a prey. Not always, however, would it fall a resistless prey, or die unrevenged, for there can be little doubt that, with the advantage of position, the stroke of the head of this slight but active reptile might occasionally reverse the picture, and insure victory to the less powerful of the combatants.

The plesiosaurus and ichthyosaurus were but two of several genera of large reptiles whose more or less aquatic habits have been the cause of their remains being preserved in the lias. Some, as the teleosaurus, resembled the *garial*, or crocodile of the Ganges, and were more abundant in more modern deposits—others, such as the pterodactyl, being dependent on land to some extent, are rarely met with. Probably many of the new red sandstone reptiles extended into the lias, and ranged through the whole period; but these were chiefly confined to shoals and low flat shores, and are thus not found in the deep water mud.

After the termination of the deposit of that great mass of calcareous mud just described, and when the transition to the true oolitic period commenced, we find distinct intimation of the near presence of land clothed with vegetation, consisting chiefly of *zamias*, *cycadeæ*, and some coniferous trees. At this time there commenced a deposit of fine calcareous mud, which was tolerably uniform from the north of France to the coast of Yorkshire, but was from time to time modified according to alternations of level in the general area of the land. Not very long after, islands appeared on what had hitherto been open sea; and these islands became in course of time the dwelling-place of small land animals.

The condition of the surface-bottom of the sea being at this time favourable for the full development of the lower marine animals, both in number and variety, we accordingly now find whole beds of shelly limestone made up exclusively of the debris of such creatures; and any one, who will examine carefully the common building stone obtained from these deposits in Northamptonshire and Oxfordshire, and even near Bath, will find these almost exclusively present wherever the little egg-like structure, which has since been assumed, does not conceal them. During this time there were many fishes, chiefly those living near shore, which also have left marks of their existence; and in some of the beds are leaves of trees, wing-cases of beetles, and the bones of land animals.

After about three hundred feet of such strata were deposited in the west of England, we find beds which were manifestly formed in the immediate proximity of land; and it is interesting to speculate, as we are in a condition to do, on the possible nature of its inhabitants. Let us endeavour to recall some of the main

points that might then have attracted attention, as differing from the present condition of European land.

Let us, then, imagine ourselves placed on some projecting headland, commanding a view of the open sea, which at that time covered the greater part of our island, and permitting us to watch the progress of events near some low flat island; a sandy shore of the oolitic period, on which a few palms are seen, and which present a back-ground of pines and ferns towards the interior of the country.

Here, near the shore, would appear one of those crocodilian animals, with its long, slender snout, and fin-like extremities, admirably adapted to swim and obtain prey in the water, but hiding in the mud, and lying for hours like the trunk of a tree on the muddy bank.

At a little distance in the shallow water numerous representatives of the plesiosaur and ichthyosaur would be seen, and with them some curious forms of reptilian animals, combining some of the peculiarities of these two genera. We may imagine one of those, the pliosaurus, as it advances its great mass through the water. Its huge lizard-like head contrasts strangely with the fish-like body which is attached to the head without an intervening neck, and the absence of a powerful vertical tail is fully made up by the extremities, which are several feet in length, and admirably adapted to be used as fins. With one stroke of these fins we see the whole enormous mass shoot along with terrible rapidity; and a large shark, pursuing and feeding upon other prey, in a moment falls a victim to the greater strength and activity of this marine monster.

Quitting the prospect thus presented at sea, let us next turn our eyes towards the land. Here the long-snouted crocodile, whom we before observed gorging himself with the fish in the shallow bay, sleeps either half buried in the mud on shore near a jungle, or in an estuary. His length is perhaps 18 or 20 feet, and he is admirably contrived to swim and dive, and attack his prey in the water; but on land, like many animals of this kind, he is more helpless. Now, however, the crashing sound accompanying the motion of a heavy animal through brushwood is heard approaching rapidly; and soon a monster is seen, taller than an elephant, but not provided with a long trunk to twine about and pull down the branches of trees. Instead of this we perceive a prodigiously long and powerful but narrow snout, armed throughout with the most singular arrangement of sharp and strong knife-like teeth. Onward comes this giant of the plains. To its head is attached a moderately long neck, and a body half as long again as that of the elephant, and thick and massive in proportion. Huge living columns support this body, and are based on feet each of them large and strong enough to crush a dozen pigmies like ourselves. With one stroke of its fore feet, armed with powerful claws, the gorged crocodile is struck dead, and it is soon devoured, as if such a meal was scarce worthy of consideration.

But let us now turn aside once more and contemplate yet another scene. Still remaining near the shore, but looking at the land rather than the sea, let us watch the golden beetles, the beautiful dragon flies, and other insects, as they flit past in all the brilliancy and cheerfulness of luxuriant nature. The lofty trees are woven together by thick underwood, and the open country, where it is not wooded, is brown with the numerous ferns which are distributed abundantly in extensive groups. Here and there we see a tree overturned and lying at its length upon the ground, preserving indeed its shape, but thoroughly rotten, and serving as the retreat of the scorpion, the centipede, and similar noxious insects. A few small quadrupeds, about the size of rats, may be

distinguished at intervals, timid even in the absence of danger, and scarcely venturing to appear without the greatest precaution. These feed upon the grubs and larvæ of the flying insects, and on the various species that live upon or burrow under the ground.

What, however, is the strangely formed animal that now appears running along upon the ground like a bird, its elevated body and long neck not covered with feathers, but with skin, naked or resplendent with glittering scales, its head like the head of a lizard or crocodile, and of a size almost preposterous compared with that of the body, and its long fore extremities so oddly stretched out and connected by a membrane with the body and the hind legs? Suddenly this creature runs rapidly, and soon overtakes the little quadruped, and in spite of its precautions presently devours it.

PTERODACTYL—GREAT OOLITE.

Soon another strange phenomenon is presented—a mailed creature in the air, of no contemptible size, and realizing, or even surpassing in strangeness, the mythological accounts of the flying dragon, and the pictures given by the Chinese. This, however, is merely the flying reptile whose terrestrial appearance we have just described. It is the pterodactyl; its fore arm, hand, and finger extended, and the interspace filled up by a tough membrane; its head and neck stretched out like that of the heron in its flight, and the creature from time to time seizing the insects which it pursues, and devouring them with avidity. Perhaps this monster might occasionally be seen flying towards the sea and there darting down on some devoted fish, or even diving beneath the surface in search of prey, and exhibiting the most singular and perfect combination of locomotive powers yet known.

With variations considerable, no doubt, and important, affecting more or less the nature of the deposits, and for that reason, modifying the inhabitants of the sea, the picture above given may be received as one neither false nor exaggerated, however imperfect, and as characterizing the whole of the long period during which the series of the oolites was in course of deposition. From time to time coral islands seem to have been formed, but these are local and rarely extensive; at other times large quantities of mud were poured into deep water, burying and preserving the remains of animals in remarkable perfection; and occasionally, but much more rarely, sands were deposited. These beds went on alternating with one another, the limestones being always preponderant; and the undulations of the surface, which permitted so long a

series of deposits, at length seem to have terminated by the production of a very extensive tract of dry land, lifting up the ancient bed of the oolitic sea, and at once preventing further deposits.

This view is suggested by the evident proximity of land during the later oolitic period, not only with reference to the deposits going on in the British Islands, but also those covering a portion of Northern Europe. It is, however, limited to certain parts of these districts, and does not appear to be applicable beyond them; and indeed it is probable, from the nature of the deposits, that in Southern Europe and Asia Minor the contrary was the case, and that the sea was there becoming deeper, and receiving gradually fewer and fewer coast deposits. But with regard to the northern and western districts, we have evidence singularly distinct and satisfactory, that just at the close of the deposit of that uppermost bed of oolites which occurs in the island of Portland, the alternations of level were numerous, and at no very long interval; perhaps resembling in this respect what is now taking place at the mouth of the Indus, where, in Cutch, a considerable tract of land has been alternately lost and gained even within a few years. In England also (formerly, as now in India), there were great rivers, and probably deltas, and when the sea bottom was finally elevated to form dry land, a mass of sandy beds, corresponding with what is now in course of formation under similar circumstances, seems to have been deposited at the embouchure of this great stream, which must have proceeded through a land abounding with vegetation, and containing numerous animals of large size.

The land, however, which had long been advancing steadily, gaining on the sea in these latitudes, received about this time a check, and a great change took place, at first, perhaps, by alternations of level, but soon by rapid and decided depression. Deep sea soon covered the whole tract to the east and south—vast quantities of fine chalky mud were deposited, probably from neighbouring coral reefs; and a very long period elapsed, during which the great masses of sandy and calcareous beds, including amongst them the whole of the chalk, were gradually accumulated. Still land was near, for we find among the chalk, a distinctly marine deposit—fragments of bone which seem to prove beyond a doubt that not only was the pterodactyl then still remaining, but that some true birds not unlike the albatross had also been introduced.

Considered as a whole, the secondary period will now be seen to possess a well marked and very distinct group of animals and vegetables, exceedingly different in general aspect, no less than in the details of specific character from the more ancient period. This difference consists partly in the replacement of a number of strange forms of animals and vegetables by others more resembling those now living; but it consists also, and in a far more striking way, of the presence of one highly important group of animals—one, in fact, of the great divisions of the animal kingdom—in such singular variety of form, such relative numerical abundance, and so distinctly representative of the more highly organised races afterwards introduced, as to render it almost certain that the absence, or great rarity, of true quadrupeds is not accidental, nor the result of our imperfect knowledge, but a real, and, if so, a very important fact.

The corresponding characteristic of the former and earlier period is seen, as already described, in the great development of the race of fishes, which then represented, and were afterwards replaced by the reptiles. It is this substitution or representation of one class for another which gives completeness and fulness to our picture, and renders it probable that we really have a tolerable sketch of the whole, and not a mere highly coloured representation of the events passing in a single area in space, or during a short

period in time. By means of such comparative views, too, we obtain an idea of the general bearing, the harmony, the symmetry, and the perfectness of each group, and thus attain in the end more distinct and rational, and less exaggerated views of the differences and resemblances of created beings at widely distant periods of time.

In concluding the account of this period of reptilian preponderance, and especially when, in order to exhibit something of the habits in their most striking modes of action, it has been necessary to describe scenes of carnage and horror probably enacted at the time referred to, it is right to remember how perfectly accordant are such scenes with the benevolence as well as the wisdom of the great Author of Nature. They are, in fact, results compatible with the perfect goodness of the Creator, and they cannot be considered to involve any needless suffering. For ourselves as human beings, and constituted as we are, looking on death as a punishment that must be endured, and always earnestly bent on warding it off as long as possible, any premature and violent termination of life seems to involve pain and misery. But this is by no means the law of nature as regards animal life in general; and, on the contrary, the very exuberance and abundance of life is at once obtained and kept within bounds by the voracity and predaceous habits of certain tribes.

A lingering death—a natural and slow decay of those powers which alone enable an animal to enjoy life—would unquestionably be an arrangement fraught with suffering in the case of beings not endowed with reason, and not assisting one another. It would be cruelty, because it would involve hopeless suffering. A violent death is to unreasoning animals the easiest and the most natural termination of life; and it has manifestly been ordained, from the beginning, that in order to insure the greatest amount of enjoyment of life, there should be a never-failing and ample succession of individuals and species, the vegetable world providing food for some races, but the greater number taking from animals of lower organization the more directly available food which they had prepared; or, on the other hand, preventing animal matter once elaborated from being dissipated, or entirely decomposed, by taking up, even in its very last stage, the minutest organic fragments, and bringing them back to the realms of life.

TERTIARY EPOCH.

The rocks above the chalk are, and have long been designated as tertiary. In England they include but a small and very imperfect series; but elsewhere they are developed to an extent and thickness, in some places equalling, in others far surpassing, those of the older and underlying systems. Since, however, the more important subdivisions are foreign, there was, for a long time, a comparative neglect of tertiary rocks in our own country, and the actual relative position of those we have, has been only decided within a very recent period.

Following a nomenclature which has been found convenient in the other epochs, it will be desirable to consider the rocks of this newer period as divided into three principal groups, to which the terms lower, middle, and upper tertiaries seem the best that can be given. The upper tertiaries will be found to pass into deposits of the recent period.*

* The reader should be informed that the terms EOCENE, MIOCENE, and PLIOCENE, are frequently given to these three divisions. They were suggested by Sir C. Lyell, who, finding that the fossil shells of the various divisions of the tertiary epoch include gradually a larger proportion of existing species, introduced the words in question to designate something of a numerical ratio which he then believed to exist. Thus, *eocene* (from ἠώς, dawn; καινός, new) was intended to include rocks in

Lower Tertiary Rocks and Fossils.—There seems little doubt that the large and widely-spread deposits on the borders of the Mediterranean Sea, in many parts consisting of thick beds of limestone, loaded with a peculiar fossil, resembling a piece of money, and thence called *nummulite* (see page 118), but elsewhere containing hardly any fossils, must be regarded as the true base of the tertiary series as at present known.

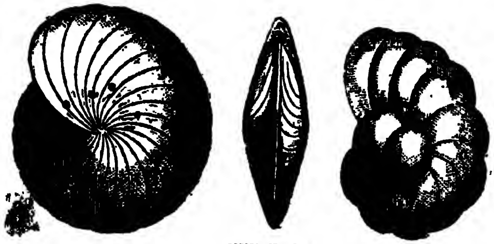
Beds of the same age appear at the margin of what are called the London and Hampshire basins, and also around the Paris basin; but they are here of inconsiderable thickness. In Africa, on the north-eastern shores and in Asia, on the south flank of the Himalayas, extending to Calcutta on the east and Bombay on the west, these beds are no less distinctly traceable. They are also found on the shores of the Black Sea, in Dalmatia, Carinthia, Transylvania, Hungary, and Poland. The deposits are usually calcareous, and appear to have been chiefly made in deep sea. The fossils, however, include not only the foraminifera, of which the nummulite is an example, but many shells, as well land (*physa*, see p. 118) and freshwater (*cyclas*) as marine (*cardita*), numerous fishes (*rhombus*), some birds, and several land quadrupeds. The beds have therefore been formed under various circumstances, though about the same time.

Reposing on these oldest tertiaries, and in many places appearing to form part of, or replace them, are a number of beds admirably developed near Paris, and somewhat extensively seen near London, in Hampshire, in the Isle of Wight, and again in Belgium and the South of France. These are very varied in their character. In England, they include an important series of clays (London clay) reposing on sand, and overlaid by other sands, and by freshwater and marine limestones.

Above these come in a large series of deposits, whose total thickness in England amounts to nearly fifteen hundred feet, recognised as a distinct group, and corresponding with certain coarse limestones and peculiar sands near Paris. Above these again are marls and limestones in England, represented by soft sands (*molasse*) in the south-west of France, and a limestone deposit well known in Malta, and extending over various parts of the Mediterranean, hitherto regarded as belonging to the middle tertiary period, but determined by Professor E. Forbes to be really a part of the older series. The lower and middle parts of the series thus described, contain numerous interesting fossil remains, among which are a multitude of very remarkable fragments and complete skeletons of quadrupeds. (See Cut, page 119.) There are also numerous fruits, and some corals and crustaceans, with shells and fragments of fishes met with in some localities, of which the Isle of Sheppey, near the mouth of the Thames, has long been remarkable. Reptiles also are here found, proving that the condition of the country, and probably its climate, were extremely different from those at present existing in these latitudes.

In the Paris deposits are found some beds of gypsum, which are at once useful in themselves, as yielding the material of which is manufactured "plaster of Paris," and also of extreme interest to the naturalist, as containing those fossil bones, whence has been reconstructed, by Cuvier and others, an entire menagerie of extinct organic beings.

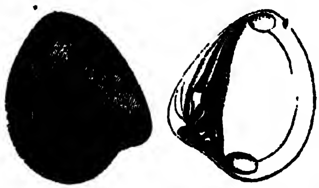
which a faint indication of existing species (less than five per cent.) was first perceived—*miocene* (μειων, less; and καινος), those in which a minority, or less than half the species, were recent, and *pliocene* (πλειων, more; and καινος), those in which a larger number than half were recent. As these names appear to offer no special advantage, and have been misunderstood to intimate a decided and abrupt transition and definite percentage, which does not exist in nature, it may be better to avoid the use of them, and adhere to the simpler and equally distinctive terms above-mentioned. It may also be stated here, that by some geologists the middle or secondary rocks are called *meso-zoic*, and the newer or tertiary *caino-zoic*.



NUMMULITE.

CYCLOSTOMA ARNOLDII.

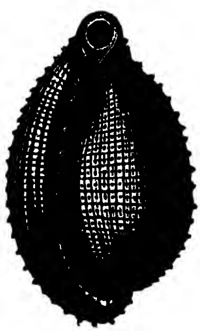
PHYSA COLUMNARIS.



CYCLAS ANTIQUA.

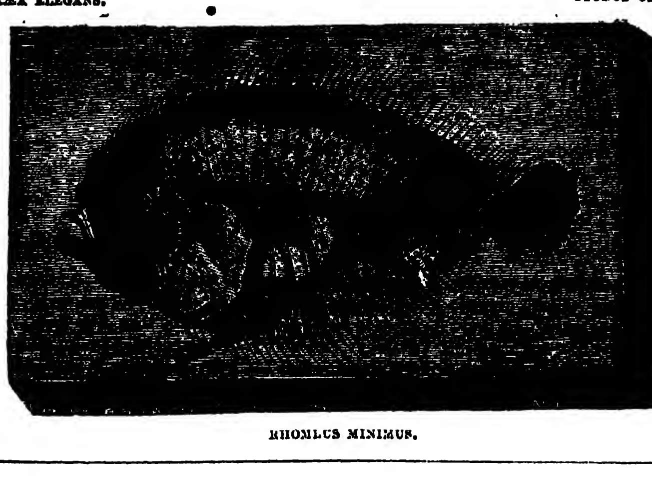
CARDITA PECTUNCULARIS.

CERITHIUM HEXAGONUM.



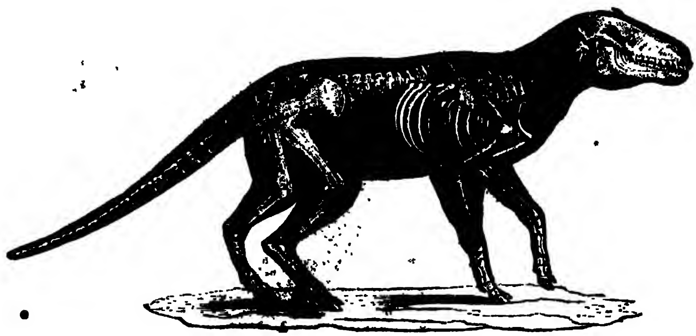
CYPRÆA ELEGANS.

OTODUS OBLIQUUS.



RHOMBUS MINIMUS.

These beds were long celebrated for the readiness with which they yielded these treasures, but they have ceased of late years to deserve their reputation. North America presents a number of beds of the period we are now considering, chiefly developed in the southern states, and consisting of greenish sands, marls, and a peculiar white lime-



ANOPLOTHERIUM COMMUNE (*Paris basin*).

stone. Most of the fossils are closely allied to European forms. Even in South America there have also been found representative deposits.

Middle Tertiary Rocks and Fossils.—In England this division is but scantily shown, and includes only a few bands of sand, gravel beds made up of shells, and some marls. These have been found on the coasts of Suffolk and Essex, and range into the interior.

Very large masses of rock of various kinds form the corresponding deposits in the south-west of France, the east of Germany, and various parts of the Mediterranean shores; and others, entirely different in appearance, have been recognised on the flanks of the Himalayas and in South America.

The English middle tertiary deposit is called the coralline crag, and contains numerous small corals, many shells, both univalve and bivalve, and a few remains of crustacea and fishes. Quadrupeds and reptiles are extremely rare.

In the valley of the Rhine, on the flanks of the Alpine chain, in the great valley of Switzerland, in the valley of the Danube, and in northern India, the characteristic peculiarities are in each case distinct. Thus, while the loose sand of the Swiss *molasse** is widely spread, and contains a few shells and some remains even of palm vegetation, we find, in the valley of the Rhine, beds containing the bones of a gigantic quadruped, the dinotherium (see page 123), while the tertiaries of northern India contain numerous indications of a complete fauna, including, amongst a number of species little different from the present inhabitants of the country, a multitude of others altogether new, and departing widely from known forms.

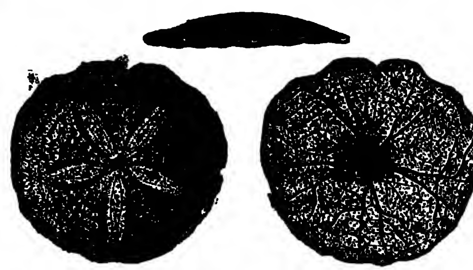
The fossils of the middle tertiary period are not generally so varied and essentially characteristic as those of the older and newer deposit, although India forms a great and interesting exception. Some of the less common and more easily recognised shells and other fossils are represented in the next page; and it may be observed that this group represents two genera of the comparatively rare family of pteropoda, and two instances of shark's teeth. There is also a crab, a foraminiferous shell (*textularia*), and

* Not the molasse of the south-west of France.

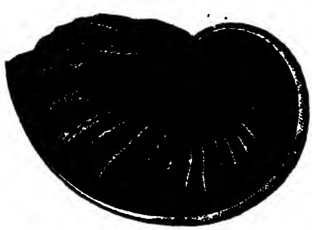
one of the flat sea-urchins, or star-fishes of the time. Many of the shells approach so near in appearance to those now found in adjacent and distant seas, that no useful purpose would be answered by figuring them here. It is right to state that a large flora of this period has been determined, presenting a mixture of exotic forms now peculiar

GROUP OF MIDDLE TERTIARY SPECIES.

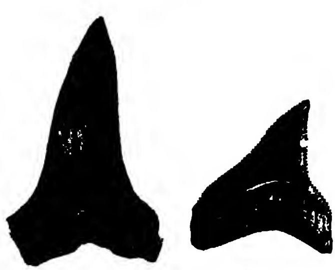
TEXTULARIA.



SCUTELLA SUBROTUNDA.



CARINARIA.



TEETH OF SHARK.

CANCER MAERSCHEILUS.

to warm climates, with others equally characteristic of temperate countries. Thus palms, a bamboo, and others of the same habits, are found associated with leaves of oaks, elms, &c.

Upper Tertiary Rocks and Fossils.—Of this part of the period there are many subdivisions. The sub-Apennine limestones, contemporaneous with part of our Suffolk crag, are represented in South America by a vast expanse of rock, containing numerous organic remains of the most singular and interesting quadrupeds. Caverns in limestone rocks, frozen cliffs on the shores of the Polar Sea, freshwater deposits, and osseous breccias in central France, Italy, and many other countries, all appear to belong to this part of the tertiary epoch, and all present numerous objects of interest amongst

the fossils they contain. Nearly fifty species of quadrupeds, and half that number of birds, have already been described, all more or less differing from existing forms—some departing widely, others approximating closely. The various groups of deposits of the period have been thus classed :—

1. Recent Deposits, including raised beaches on the English shores; the *lehm*, or *loess*, of the Rhine valley; the *tchornozem*, or black earth of the great plains of the Caspian Sea and Lake of Aral; the *regur*, or cotton soil of India; and large tracts of recently elevated land in Patagonia.

2. Drift, including stratified sands and gravels, left by glaciers and icebergs; unstratified clays and gravels, with boulders, common in the Clyde valley, and locally called *till;* the mammaliferous or Norwich crag of our east coast, and the sands of Bridlington, on the Yorkshire coast; and a number of fresh-water beds, consisting of sands, marls, and gravels.

3. Sandy deposits, of which the *red crag* of Norfolk and Suffolk, the calcareous marls and sands of the Sub-Apennines, the great limestone of Sicily, the vast deposits of lignite, or *brown coal*, of Germany, and the marls and limestones of Œningen, near the lake of Constance, are the chief that have been described, though others, probably of equal magnitude, remain to be noticed.

It would manifestly be out of place here to describe at length any of these numerous and varied deposits. Each may be said to possess some point of special interest—sometimes local, but more frequently general; and each might well be the subject of a separate chapter.

Thus the Œningen beds are remarkable for their rich variety of fossils, including quadrupeds, fishes, and many plants. The lignites, associated often with plastic clays, and fine deposits of a kind of siliceous paste, made up of the debris of infusorial animalcules, are no less interesting, for the almost incredible extent to which the vegetable matter has been accumulated; while the limestones and marls of Italy are, and long have been, the subject of elaborate descriptions, and form connecting links between ancient and modern times.

ERRATIC BLOCKS IN MASSACHUSETTS, UNITED STATES.

But the drift, under whatever name it is described, affords other equally interesting subjects for consideration. In some places are vast boulders of rock, transported hundreds of miles from the parent rock

(see the view in the Cut, page 121), in others are huge masses of smaller blocks, collected from various quarters. Here the ground on which these heaps rest has been smoothed and scratched by the passage over it of large quantities of material; while not far off similar gravels are stratified, and contain bones of many quadrupeds, and even of birds. The cause of all these phenomena is apparently to be traced to the passage of currents of water in shallow seas, the currents often floating icebergs of large dimensions; and when, on any occasion, these icebergs are stranded, the cargoes of transported material, which such natural rafts bear along with them, are necessarily deposited at the sea bottom, on the melting of the ice.

The last change, the disintegration of the surface when once permanently elevated, the gradual accumulation of vegetable matter of various kinds, and the preparation of land for the habitation of the larger quadrupeds, is a subject still obscure in many of its details, but becoming more clear as we advance in the right direction of geological investigation; and difficult as the investigation may seem, naturalists are really now in a condition to judge a little of the probable aspect of the earth during these later revolutions in the way formerly attempted, with reference first to the palæozoic, and and afterwards to the secondary period.'

Outline of Tertiary Scenes.—Making use of the various means that exist, by the help of careful observation of actual fossils, and reasoning by analogy, it has been concluded that the tertiary period in Europe, Asia, and in North America, exhibits a series of changes during which these parts of the world were gradually assuming their present physical condition, while the inhabitants were becoming more and more like those now occupying the same latitude. The changes thus involved are both considerable and important. In those very spots which men have made the centres of civilization and commerce, in the immediate neighbourhood of the two great metropolitan cities of England and France,* we also find, by a somewhat strange coincidence, the most striking and interesting remains of the earth's ancient condition, and convincing proofs that the former inhabitants were as widely different from those now indigenous, as these are from the animals at present found in Eastern Asia.

It is not unlikely that the land at that time, in our latitudes, consisted of islands deeply indented by bays and inlets, some of them perhaps of large size, having considerable rivers, depositing various beds of mud and sand. The neighbouring seas were tenanted by many large sharks, by gigantic rays, by sword-fishes, saw-fishes, and many others now almost confined to the eastern extremity of the Old World, or found in the Gulf of Mexico. With these were many animals inhabiting shells, now also confined within similar limits; but there were also with them a number of fishes and shell-fish, far more closely allied to the species now living on our own shores. The coast-line of this sea seems to have possessed peculiar features, being clothed with rich and almost tropical vegetation to the water's edge, and exhibiting in abundance palm-trees, cocoa-nuts, and many of those shrubs which characterize the islands of the eastern Archipelago. The rivers, and perhaps the sea near the coast, were peopled with crocodiles;—turtles, and tortoises of various kinds, lived either in or near the water; and in most respects we must seek for the nearest representation of such a combination at very distant spots, and under very different climatal conditions.

Nor was the state of existence in the interior less striking and peculiar. Troops of

* It is singular enough that the same may be said, with equal correctness, of the capital of Belgium, which is placed on a patch of tertiary rock, nearly of the same age as the basins of London and Paris, though not so remarkable for its fossil contents.

monkeys, some of them of large size, might then have been seen skipping from branch to branch on the forest trees. Opossums were associated with the squirrels, and a racoon was among the quadrupeds common in western Europe, while wolves and foxes had already been introduced, and species were co-existent with those animals now widely removed from association with them. Serpents of various size, but some altogether gigantic, assisted in the destruction of the numerous tree-quadrupeds living on vegetable food. Birds, too, were then abundant, and amongst them we find that the tribe, now the natural enemy of the serpents, was also present.

OLDER TERTIARY QUADRUPEDS.*

But it is most probable that the chief deposits, of which we have cognizance, were made either near rivers, or not far from extensive marshes. Just as at present we find the low and unhealthy swamps of Sumatra, and extensive tracts in South America, peopled by the tapir, so then there was a complete group of nearly similar animals of the extinct genera, *Palæotherium* and *Anoplotherium*, adapted to similar localities. Very various in size and proportions, and very different in their habits, some of these (the *Anoplotheres*) swam readily, and lived chiefly in the water, being provided with a long powerful tail, serving as a rudder. Others, again, referred to the same genus, tripped along lightly on the borders of the marshes, feeding, like the musk deer, on the aromatic shrubs that were there abundant. Others, more timid, and constantly on the alert, were enabled to course rapidly along, and escape by flight, or conceal themselves in their burrows beneath the surface. Groups of these animals are amongst the restorations preparing for the Crystal Palace.

A little later in the period, and when a larger quantity of land had been elevated, new and more gigantic races were introduced. Among these was one group of true elephants; another, of equal or even greater size, the *Mastodon*, whose teeth seem adapted for food somewhat tougher than that which the alternate plates of enamel and bone in the elephant were enabled to crush, and whose body was somewhat larger; while a third (the *Dinothere*), was more like the tapir in its habits, but more gigantic in its proportions. This latter animal dwelt in the swamps, and its skull and formidable tusks in the lower jaw seem to point to habits almost exclusively aquatic (see Cut).

After remaining for some time in this condition, the land seems to have become more extensive, to have been clothed with abundant vegetation chiefly of forest trees,

* Of the animals here represented, the upper quadruped is an Anoplothere, and the two lower Palæotheres. The small species was about the size of a pig. On the right is a crocodile, and the vegetation is chiefly of palm trees.

and to have been peopled by numerous large ruminants, and by many of those carnivorous animals of large size, now confined to the eastern and southern districts of the old continents. This was the last condition before the introduction of man upon the earth.

DINOTHERIUM.

While Europe was thus undergoing a series of changes which occasioned or required the introduction of many new groups of animals, and the destruction of many that had long existed, the eastern part of the great tract of land, then in course of elevation, seems to have been convulsed by fewer of those destructive disturbances, and to have retained, for a very long time and with few modifications, its early tertiary fauna.

A vast basin of fresh-water appears to have extended over a great part of Northern India and Malacca, on the shores of which lived a numerous and varied population of elephants, horses, hippopotamuses, deer, and many other vegetable feeders, with a corresponding race of carnivora of large size and great power. The earth there groaned under the pressure of a huge tortoise, whose monstrous proportions it is scarcely possible to realise; and numerous other animals existed, of strange habits, and yet stranger appearance, to a knowledge of which we have only yet begun to attain.

The elephants, then very abundant, were not confined in their range to Northern India; they extended also over the vast plains of Tartary into Siberia, and fed on the scanty vegetation distributed over a district which now has become absolutely bare and desolate.

It is, however, not likely that at this time the land reached so far towards the North Pole as it does now; and there was certainly towards the latter part of the great tertiary period sufficient vegetable food, in these vast tracts, to support wandering herds of some of the most gigantic land animals, including many groups, which at present, in consequence of physical changes, are confined entirely to much more southern and warmer districts.

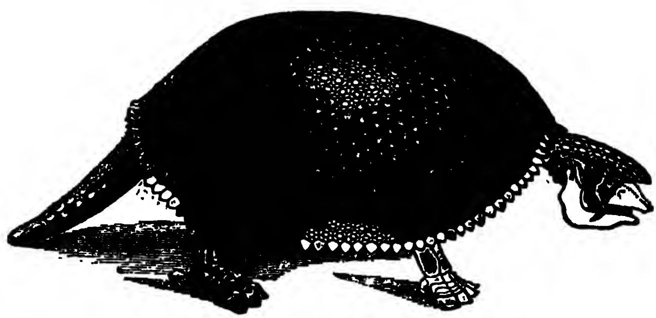
At this same period, in South America, there existed a continent of the same general shape as at present, but much narrower, and with less lofty mountains on its western side, gradually becoming elevated, though, with occasional intervals of repose, covered with vegetation, and having large and deep rivers.

On this land were tribes of edentate or toothless animals,—the gigantic types of the sloth, the armadillo, and perhaps the ant-eater. Of these animals, numerous skeletons, perfectly preserved, afford us means of re-constructing them in every detail, and we are enabled to speak of their peculiarities and habits, as if we saw them bodily before us at the present time.

In the vast forests of that day, there moved about, slowly perhaps, and with some little difficulty, a singular and clumsy looking monster; its body larger than that of an elephant, and its hinder extremities many times thicker and stronger in proportion; endowed with a degree of resisting strength, compared with which, almost every existing animal would rank as powerless. The habits of this creature were, it may be sup-

posed, rather peculiar. Judging from its heavy hind extremities and powerful tail—the arrangement of its fore-legs, in which it somewhat resembled the bear—the nature of its head and teeth, and the form and strength of its claws, we may safely imagine it performing the task of the modern sloth, its nearest representative, but enabled to root up and pull down the trees of the forest, instead of climbing to strip them of their leaves. The creature here referred to is the *megatherium*, and there were several smaller but still gigantic animals similarly constituted, and assisting to clear away leaves and twigs, by bringing their powerful though sluggish limbs to bear upon the task. The *mylodon*, one of these, was nearly as large as a rhinoceros, and of it a complete skeleton may be seen at the College of Surgeons, as well as a restored figure in the Crystal Palace Grounds, reconstructed from the skeleton, by Mr. Hawkins.

At present, the armadillo clears away the decaying wood and offal of all kinds in the Brazilian forests, and a magnified representative accompanied the megathere. The



GLYPTODON.

glyptodon, as this animal was called, is known by a complete specimen of the hard, horny covering or shell, also in the College of Surgeons; and the length of this specimen is nearly twelve feet on the curve, from the tip of the tail to the snout, while its height is between four and five feet.

Large rodents, or gnawing animals, horses, and several other species nearly allied to existing races, accompanied these singular animals.

It is extremely interesting to find that at the same period the great island-continent of Australia was peopled, as it is now, by a group of animals perfectly distinct from those inhabiting the rest of the world, and characterized by similar peculiarities of structure. Gigantic marsupials then lived, representing the elephants and even the larger carnivora of Asia; but, with the exception of the mastodon, there were, it would seem, no generic forms common to this great district and the rest of the land in the eastern hemisphere.

The islands of the South Pacific Ocean of this same hemisphere may, perhaps, when fully investigated, lead us to some knowledge of the great continent which once, probably, extended across from Australia nearly to Madagascar. Gigantic birds have already been found in New Zealand, and these are the ancient representatives of the apteryx and of the dodo, the former a New Zealand wingless bird, and the latter an extinct species found in the Mauritius, singularly analogous to the dinornis in some important points of structure. Perhaps we may yet hope to recover further indications of the inhabitants of a district which seems cut off so singularly from the rest of the world, and which, in so large a part, is now buried beneath the waves of the great Pacific Ocean.

In all the instances where we obtain a knowledge of the extinct animals which flourished during the tertiary period, we find them grouped together, the grouping being gradually more and more limited to existing zoological and botanical kingdoms as we advance towards the newer part of the series. It is a very striking feature in this distribution, that at a period with respect to man very remote, but geologically modern, many animals, now limited within narrow bounds, were once widely spread; that many generic forms, now represented by species few in number and small in size, were anciently varied in form, and infinitely abundant; and yet that the absolute limits of natural families, forming larger groups than genera, have scarcely undergone modification. Thus we see in Europe, in Asia, and in Australia, and also in South America, that the great natural families, whether of pachyderms, marsupials, edentates, monkeys, or others, are still spread over similar tracts, and still cut off by similar abrupt and unaccountable bands. The elephants, the rhinoceroses, the hippopotamuses, and other gigantic forms, once commonly associated in England with lions, tigers, hyænas, and bears, have now passed away entirely; but they are represented by the pig, the wild cat, the fox, the badger, and others, although no doubt they are also replaced in great measure by the more useful domestic animals introduced and fostered by man.

Vast and important modifications of the earth's surface, in this part of the world, have, however, beyond a doubt, taken place within a comparatively recent period; and it may be that the depression of the surface which separated England from the Continent, and the British Islands from one another, is even continued, and is producing effects by no means trifling or unimportant, while at the same time many districts of Northern Europe are undergoing elevation.

There can be no question that great physical changes of this kind must and wil produce corresponding changes with regard to the animals and vegetables natural to the climate; although man, with his cosmopolitan habits, and his power of modifying conditions of existence, and acclimatizing various organic beings useful to him, greatly checks, and often entirely conceals the effect thus produced.

Conclusion.—To complete the history of the earth, it is necessary that we should possess, as far as possible, an account of the last great changes that have affected its surface. This can only be attained by a long-continued and faithful record of the agency of existing causes; and this record it is in the power of every one, who has the means of observing Nature, to render more valuable and more complete.

It is undoubtedly the case, that of the knowledge we already possess in Geology, a large part consists of observations made in particular localities, often without much consideration of the circumstances of the adjacent rocks. It is seldom that reference has been made to similar rocks elsewhere, or to the result of similar conditions in rocks of different geological age, and still more rarely have the various natural history conditions, affecting whole groups of rocks, and together forming only one deposit, been taken into consideration. And yet it is no less certain that, without this enlarged view of all the facts of the case, no important or valid induction can be obtained, and no satisfactory conclusions in geological theory ought to be expected.

The ultimate object of geological investigations is, however, not so much the discovery of abstract facts concerning the crust of the globe, as a determination of the laws according to which successive modifications have been by degrees elucidated. Each one of these laws, as it is discovered and applied, leads to fresh and more important knowledge concerning methods of investigation, and is thus of immediate practical benefit. Tested by knowledge already acquired and applied to educe new

facts, each law does in fact assist in discovering the rest, and thus every generalization, and even every suggestion that admits of wide application, brings us more and more near the last great object, and is of direct advantage to the progress of science. Whether hypotheses thus put forth are ultimately found to be true, or whether, however useful in the existing state of knowledge, they are in themselves unsound, there is still advantage; for in either case progress is made.

In thus endeavouring to point out the advantage and use of those generalizations which many who wish only to apply their knowledge practically might perhaps pass by as not adapted for their purpose, it is desired to impress the reader with the sincere conviction, that without sound general views there can be no safe practical use of any science. And in Geology especially, where arbitrary and false conclusions might readily be drawn from partial though very extensive knowledge, it is the more necessary to guard against the very natural feeling that *mere theory*, as general views are sometimes called, is little more than an amusing chapter of romance. General knowedge, in a subject like this, is in fact the only knowledge that has any value; for a power of comparing, based on such information, is the only thing that can be useful.

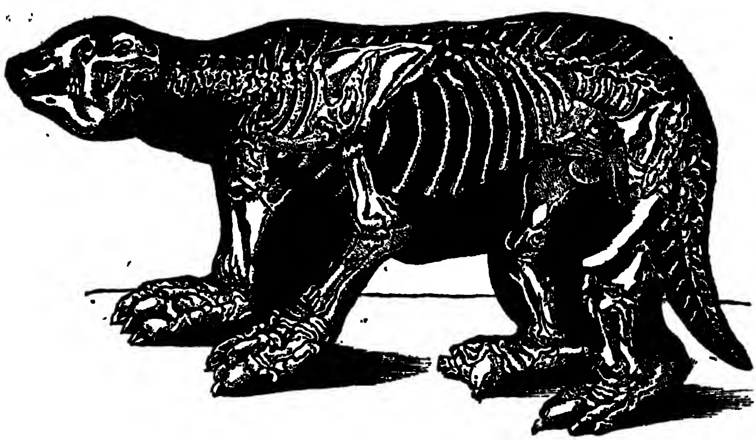
But, on the other hand, there is no intention, while thus advocating general knowledge, to detract from the value of minute knowledge on matters of detail. This also is necessary—absolutely necessary—but it is only available when it can be brought to bear by a due appreciation of general views, connecting isolated facts in a reasonable way.

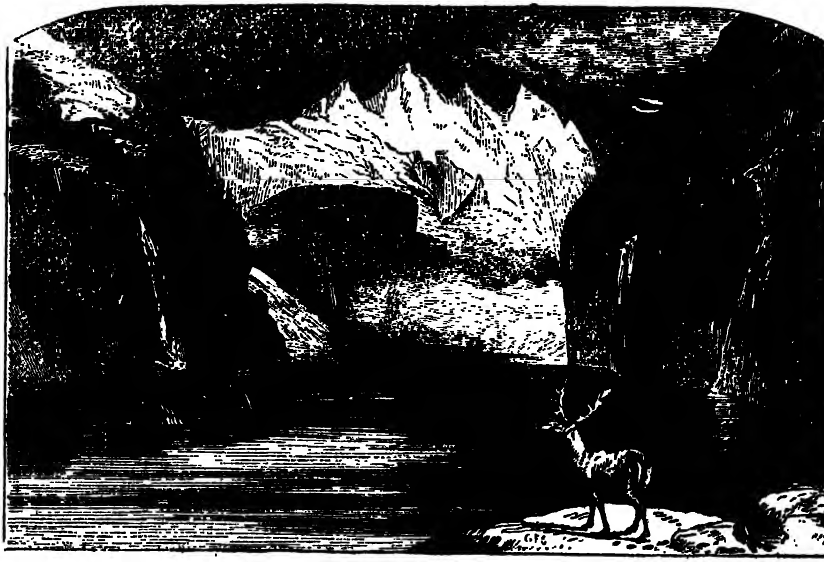
The history of geology shows, in a striking manner, that this is the case. Few sciences have advanced so rapidly, and few have had such violent opposition to contend against. Facts have been accumulated, and have been allowed to accumulate, because it is difficult to contend against them individually; but every attempt to group these facts, and obtain reasonable general views from considering them, has been met by an array of determined opponents, who have exclaimed against admitting any conclusions whatever that at all opposed preconceived notions. Still the conclusions have been drawn; one after another has approved itself by simply appealing to the reason and the senses; and, although the desire of opposition remains, all the points at first demanded have been conceded in turn.

Each generalization has, however, induced the discovery of new facts, and these again of new conclusions. Geology has been at length recognised as involving legitimate subjects of inquiry, and the world is now beginning to discover that it may also involve questions and conclusions of the greatest importance, and the most direct practical utility.

And if, in spite of the efforts that have been so successfully made, our science does not yet occupy its true position, it is at least satisfactory to know that it is advancing rapidly towards it, and that the time is gone by when its progress can be seriously interfered with by the prejudices of those who have not made themselves acquainted with its facts, or have imperfectly studied its conclusions. On the one hand, it is willingly recognised as lending important aid to men engaged in the practical pursuits of life, such as mining, engineering, and agriculture; and, on the other hand, it is beginning to be felt as no derogation from the power and wisdom of the Creator, that in the plan adopted for the construction and carrying on of our earth, and of the material and organic world, everything was foreseen from the beginning, and formed part of the plan—that everything succeeds in its time and place without external interference, and without risk of injury; and that each organised being performs the task allotted to it, and

retires when its work is done, having assisted to carry out, to the best of its ability, the one great and uniform system. It is because the system is so uniform and so perfect, that the intellect of man enables him to discover the method of arrangement adopted, and make use of the discovery for his own purposes, and to his great convenience and advantage. It is thus also that the study of the earth's crust, instead of being a merely curious and vague speculation, has become the means of obtaining with facility the various materials of value which are at present beneath the surface, and of judging concerning the probable condition of that which is out of sight, although there is no external indication of its existence.





THE KANDAL STEIG, SWITZERLAND.

PRACTICAL GEOLOGY.

Introduction.—The object of geological investigations and the general result of such inquiries being understood, it remains to consider the various modes of its application to practical purposes in useful detail, so that we may clearly prove that this science, which not long ago amused the public mind, and alarmed the timid with vague speculations and unfounded theories concerning the origin of things, now involves much that is absolutely necessary to be known, and has become an essential part of sound education; being, in fact, as important to the engineer and miner as astronomy is to the navigator.

Since, however, it is the case that geology embraces a wide range of subjects, some of which bear more directly on the natural history of living and extinct races of animals and vegetables, while others are more strictly mechanical,—and that the latter are those chiefly concerned in the practical applications with which we have to deal,—a very brief summary of such facts may be useful in entering on a new department of the subject.

It will appear, on a little consideration, that the facts in question are of very distinct kinds, and may be considered separately; for we may regard the earth's crust either as the place upon which, or within which, various operations are to be performed, or we may regard it as the great depositary of all useful and valuable mineral substances, of whatever nature. Thus the agriculturist will regard the earth and the rocks present in his district as providing the soil, and supporting the plant mechanically; but he may also look for valuable minerals to mix with his soil on the surface, and may be obliged to consider what hidden but determinable facts will interfere with or assist his draining. So, again, the architect and engineer will require to dig in some

places for stone and clay, in order that they may erect some structure in another place, where it is important that the foundation should be sound, and where no unusual difficulties need be anticipated. And so also the miner, while he is merely anxious to extract mineral wealth, must also regard and carefully estimate the difficulties he will have to contend with, while piercing to great depths beneath the surface, or burrowing to a distance within a hill.

Now, in order to understand the applications of geology thus presented, it is necessary to be familiar with certain principles and facts, relating chiefly to those masses of matter already described as *rocks*, and concerning which it is important that the practical geologist should know both their mechanical and chemical condition, and their mechanical position. It has been the object, in the preceding pages, to present these to the reader in their simplest and most comprehensive form.

Such facts duly appreciated, and the basis of geological science once laid, it is useful to notice how completely, not only the earth's structure but the habits and even civilization of its inhabitants, corresponds to this geological condition. Thus in our own country it has been often observed that the inhabitants of the mountain districts differ much from those of the plains, while those of the lowlands vary according to the nature of the underlying rock, because that influences the cultivation.

The geological structure and configuration of any country are the main foundations of its physical aspect; and the various operations of elevation, depression, and denudation, which it is the object of the geologist to study, are in effect the causes of all modifications of the aspect and structure as originally impressed. Thus the mere fact of a line of hills in a country or a district, sloping gradually on one side and much steeper on the opposite side—or elsewhere, of hills rising regularly and with monotony —will of itself mark the physical cause of such appearance, whether it is due to a distinct elevation, or to the outcrop of some hard bed. Wherever distinct and definite physical features occur, some geological cause may always be traced; and, on the other hand, every important geological event that has last happened in a district, is indicated by physical features. A knowledge of this is often extremely useful to the traveller; for in this way he may determine the probable direction, or even the possible existence of rivers and mountain ridges, and also the places where natural mineral riches are likely to be found.

The nature and use of geological maps and sections—of which many and excellent examples are produced by the geological survey of Great Britain—may also be recognised in their application to important practical questions constantly arising in agriculture, agricultural engineering, architecture, civil and military engineering, and mining. Each of these pursuits and professions having reference to material obtained from the earth, and also to the earth as the basis of operations, involves many facts of direct geological interest. It is only by a knowledge of geology, and of the mode of applying such knowledge, that much progress can be made in the higher and more suggestive departments of these sciences; and it will not be considered that there has been any unnecessary consideration of details in what has been said in previous pages concerning the nature of rock masses, their chemical composition, the mode in which they were aggregated, and the changes they have since undergone. These facts being the foundation of practical geology, are in every way worthy of careful consideration, and cannot be too well understood or too often thought of by practical men.

Whilst the applications of geology to agriculture, engineering, and mining, are direct and immediate, and will require each in its turn the careful attention of the student,

there is one other less manifest, but equally connected with the subject, that may be regarded as preliminary. It is not alone to mechanical arts and appliances that the study of nature is essential. It is equally so to those who would represent the varied physiognomy of nature in its rocks and mountains, hills, valleys, and plains, and who for this purpose learn the arts of drawing and painting, and apply them to represent the forms and colours that please the eye and instruct the intellect. The artist, as well as the engineer, and the critic in art as well as the artist, require knowledge and science, that the one may produce, and the other recognise and appreciate, a true transcript of nature.

APPLICATION OF GEOLOGY TO THE FINE ARTS.

Neglect of the Study of Natural History.—The general principles of Natural History, in the extended sense of the term, have rarely been the object of thoughtful study, either to the artist or the critic of art. This has, perhaps, been owing to a prevalent notion that such knowledge would tend to the frittering away of power in minute detail, and might injure ideal truth, which it is the highest glory of art to attain, by dragging down the mind to the contemplation of what is mechanical, and belongs to the individual rather than the species. This danger has probably been over-estimated, and the value of truth in representation has, in a corresponding degree, been lost sight of. Lately, indeed, landscape painters generally, but especially those of our own country, have shown, by many admirable examples, the advantage of a close study of nature, and an attempt at minute adherence to this truth. The conventionalities of former ages are regarded in their true light, and men have come to believe, by the evidence of their senses, that the true ideal in landscape, as in historical painting, is to be obtained only by honest and incessant study of the works of Nature, an acquaintance with the laws of Nature, and a careful observation of the actual results of those laws traceable at all times and in all places.

But it has hardly yet been thought essential to the proper education of every one, with a view either to the practice of art, or the acquisition of a sound judgment, that he should actually know and understand the facts of Natural History, and the laws of Nature. We are all apt to regard effects, and not causes;—we look at the objects before us—not with an inquiring mind, but rather as simple facts that have no reference to each other and to ourselves; we often neglect the most important of all operations, the connecting together those phenomena that we observe; and we seldom, of our own accord, refer our sensations and enjoyments to their real sources.

It is indeed true, that since the earliest period from which the modern art of painting can date, the pursuits of science, strictly so called, have mutually honoured, and been honoured by the exertions of genius in this high and noble department of the fine arts. And whether we consider the actual details of discovery, or the grand generalizations which have been their consequence, the imitative arts have in all cases been assisted in their progress by each step made in true philosophy, and in the advance of physical science.

But although this is the case, and notwithstanding the host of glorious names that crowd at once to illustrate the fact, yet it is not to be denied that the advantage has been unequal, some departments of art having benefited much more than others. Thus, while in the great works of Raffaelle, Michael Angelo, Da Vinci, and others, we recognise the most elaborate and thoughtful truth of detail and appreciation of structure, and learn that the study of their lives was devoted to observe nature, and illuminate with their genius what they really saw with their external senses, and comprehended with

their intellects, yet were their studies chiefly limited to the delineation of the human figure, and some few of the more obvious natural phenomena essential to the elucidation of great historic subjects. There are reasons for this which it is not part of our purpose now to discuss.

Art and Science.—It is beyond question that great and successful works of art are among the most noble and the most useful of all human triumphs. Art is the expression of nature, as comprehended by the most pure and exalted imaginative powers of man's intellect; it is the means by which all the great truths of nature are communicated from man to man; it involves the great principle of illustration by which the senses become available for the transmission of new ideas; it is the agency employed to harmonize and civilize the great mass of the human race.

Science, on the other hand, may be described as the questioning and investigating of nature—the laying bare the causes of things, and the method adopted when we would analyze complicated phenomena, and comprehend the meaning of truths observed and felt. Art and science thus work together in the improvement of the human family. Without art, scientific investigation has little interest beyond the original discoverer; for it is not enjoyed and appreciated by the mass of mankind. Without illustration, adapted to the nature of the case, the discovery of general views is useless in advancing and humanizing mankind. On the other hand, art, dissociated from science, if it had already advanced, degenerates, or never rises above the false ideal of the uneducated fancy. Chinese paintings well illustrate this position. The artist, therefore, should know what science is—he should appreciate what has been learnt—he should be aware of what is possible and impossible in nature, before he gives the reins to his imagination. Science, also, must avail itself of the resources of art to be permanently and generally useful.

Art and science being thus mutually dependent, it will, I think, be manifest that the artist should not be contented with observing things as they are, but should also inquire into causes. I have already observed that this has been done to a certain extent in the case of the human figure; for it is universally admitted, as absolutely essential, that the artist should not only study the undraped figure, but even so much of anatomy as shall teach the general structure of the body—the bony framework, as well as the muscular masses and the connecting tendons. It seems reasonable to suppose that this kind of knowledge is desirable in one department of art not less than another; that if the earth herself is to be delineated, it should not be without knowledge of her actual structure; that there should be something taught of the skeleton of fundamental rock, the muscular covering of super-imposed masses of matter, the drapery of vegetation, and the thin and delicate veil of finest gauze, which, in the form of atmosphere, is the cause of so many modifications of tint, and so much that is beautiful and graceful in colour and shade.

The object, in the subsequent pages, will be to give such kind of information; and it is believed that this ground has not before been occupied. It is not indeed in the character of a critic of art, much less as an artist, speaking *ex cathedra*, that these pages are written; for the author of them is not sufficiently acquainted with art to make any such pretence. He thinks, however, that he knows enough of the subject, as thus indicated, to give useful general information; and being very deeply interested in all that relates to the science of geology, and in its application to landscape painting, he ventures to give opinions and proffer information in the hope that they may be useful, at least as suggesting matter for discussion.

The Art of Painting.—It has been often stated that the art of painting is a noble and expressive language. It must then be accurately learnt before it is fitly used; but the mere fact of its being learnt does not necessarily insure the production of great and admirable pictures, any more than the knowledge of ordinary languages does the writing of a great poem. To produce these it requires inventive genius and truth of application, as well as familiarity with its use; and being thus an instrument by which man addresses his fellow-men with the intention of communicating ideas, that kind of art will readily be admitted to be the greatest "which conveys to the mind of the spectator the greatest number of the greatest ideas." If this is so, then truth of nature, derived from a knowledge of Nature and her laws, is the only foundation of true greatness in art; for there is nothing great in falsehood, nothing pleasing in ignorance; and certainly nothing impressive can be produced by the mere repetition and reiteration of examples of acknowledged rules.

Knowledge, then, is desirable, in order that the artist may understand how nature is to be truly described; and in art, as in the ordinary affairs of life, it is well to be aware of causes as well as facts, that we may fitly perform our part in the world. The knowledge needed by the artist, with regard to natural objects, involves various inquiries, spread over many sciences, and perhaps for this reason has not yet been conveniently collected into a single and comprehensive treatise. We must resort to chemistry and meteorology, to physical geography and geology, to zoology and botany; and from each of these great and important pursuits we must seek for information concerning facts and causes which can afterwards be brought to bear for the benefit of the true and honest student of nature.

Nor is information of this kind less useful to the general reader, who has been told of facts, but has not yet brought his information to bear in any practical way on their application, whether to art or other purposes. Knowledge is good, but knowledge without thought and comparison has but little practical value. We must therefore trace the relations of these sciences, and the full though often obscure application of the laws we discover.

The facts and truths of nature, which we propose to consider and describe, relate, first, to the conditions in which matter is presented to our investigation on the globe; secondly, to the forces which affect matter, and the modifications they induce; thirdly, to the internal structure of the earth, as affecting its external aspect; and, lastly, to the way in which the earth is clothed with vegetable and covered with animal life.

In that part of the present treatise devoted to physical geography, it has been mentioned that the earth is composed of matter, and combinations of matter, presented for investigation in the three forms of solid, gaseous, and liquid. There is the solid nucleus of land, an ocean covering a large part of the land, and an aërial or atmospheric veil covering the whole more or less completely. First, let us proceed to consider the atmosphere as it affects the principles of art—a subject of vast importance and great extent, and which we can only very slightly sketch on the present occasion.

This atmosphere is a transparent veil of elastic matter entirely covering the earth, and extending to a distance of more than forty miles from its surface. At that distance, however, it is so exceedingly thin and expanded, that no instruments we are possessed of would enable us to form any notion of its existence. When it is considered that the diameter of the earth is 8000 miles, the language used in respect to the atmosphere, that it is nothing more than a thin veil, will be seen to be justified, for in reality it does not correspond to more than a coat of varnish on a terrestial globe three feet in

diameter. It is, however, important, when considered with regard to surface phenomena of the earth; and all living beings on the globe actually depend on the air they breathe for the continuance of their existence from one instant to another.

Light.—With reference to the principles of art, the atmosphere is important chiefly in its relations to light, and this partly in its pure state, without aqueous vapour, and as a substance nearly but not quite transparent, but chiefly in connection with the large quantity of water which is always present in it; sometimes held in solution in a way, and to an extent, scarcely interfering with its transparency—sometimes visible in the shape of mist, and sometimes in the apparently solid form of cloud. The atmosphere is greatly affected in all respects by changes of temperature and electric condition, and thus its phenomena are influenced by the laws governing light, heat, and electricity. From the action of such laws occur numerous changes of very considerable magnitude in relation to the condition of the air and its effect on the appearances of near and distant objects.

To the artist, light is so important in many ways as to need a special study, in order to comprehend fully its nature, properties, and effects. It is important in itself positively, as being the only means we have of clearly distinguishing and fully comprehending the various objects that surround us. In this sense it is desirable that all should know something of its nature, in order that we may learn how to make use of it, and apply our knowledge to determine its effects on various material objects. But it is very important to remember, that without the atmosphere light would be of no essential use to us. All would be positive, direct light, or absolute and total darkness. Our visual organs are so constituted as to require certain modifications of light, and such a distribution as shall insure shadows not perfectly dark. These are essential to the use of our organs of sight. If it were not for the condition of the atmosphere as it exists on the earth, light might indeed be conveyed from the sun to us, and thus reach the eye directly; but in this case, every object that interfered between the source of light and the organ of vision would produce perfect darkness; not a shadow, in our sense of the term, but a blackness or darkness far greater than anything we ever perceive or can imagine. Total darkness would occur in such case every time the sun was concealed. It would be impossible to have indirect light, for within any building where the sun could not directly penetrate, or to which there was not direct reflection, the gloom would be total. There would be nothing more than broad open sunshine, and perfect black darkness. Such would be the condition of things, were we either without an atmosphere (if that were possible), or provided with an atmosphere which was perfectly transparent, and allowed all light to pass through it without reflecting any.

Our ideas of light are, however, so completely derived from its effects as seen on the earth, and are thus so associated with the results of atmospheric action in absorbing and distributing it, that we can with great difficulty imagine any fundamental modification—although there is no doubt that the conditions of its existence might be very much altered in many respects. As it is, however, their supply of this important agent is governed and affected by a vast number of causes. Thus a certain proportion of the light coming to the earth is at once absorbed, or, as it were, annihilated; the quantity depending on the quantity of air passed through. It has been estimated, that if our atmosphere, instead of being forty miles high, were as much as seven hundred miles, and all of the same nature, this difference alone would be sufficient to insure the total absorption of all direct light from the sun before the solid surface was reached. In this case the atmosphere would be light, but the earth totally dark.

Reflection, Refraction, and Absorption of Light.—Of the light not ab-

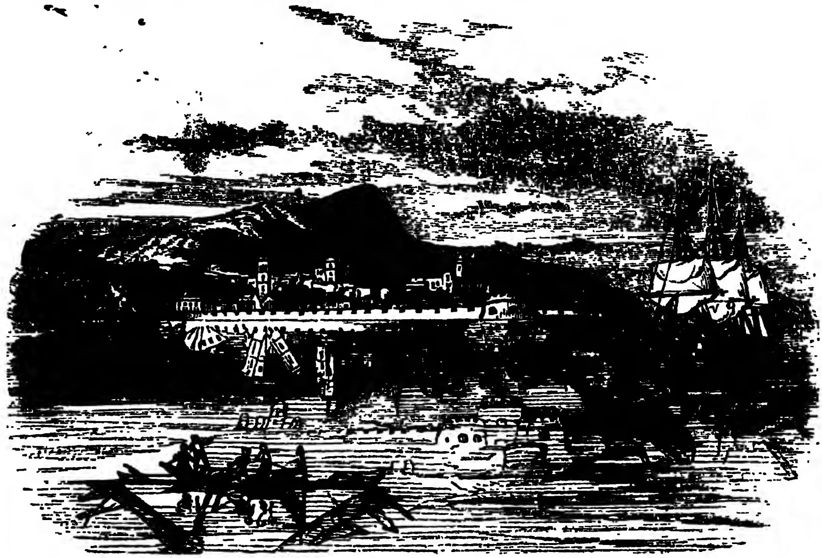
sorbed, a part is dispersed or distributed by reflection, so as to produce much illumination in the atmosphere, where no direct beams are introduced, and where there is no direct reflection from any apparent substance. When a solid body, not transparent, is placed between the sun and the earth, the rays of light (which move through space in straight lines) are intercepted, and the natural result would be, that an absolute shadow, or, in other words, a total darkness, would result. This is prevented by the dispersion of light, so that shadows never show more than a partial, and often only a very small decrease of brightness, toning by gradual degrees from the deepest obscurity at the centre, to a near approximation towards broad light at the edges. Small objects thus show less decided and less deep shadows than larger bodies, and the largest are greatly affected in the depth of shadow by the brightness of the surrounding light, and the clearness of the air. So also in the interior of buildings imperfectly lighted by windows opened in vertical walls, the direct light that enters is small, but ample illumination is obtained in consequence of dispersion. There is, however, besides true dispersion, a large reflection of light from all solid bodies. Some of black colour reflect indeed hardly any, absorbing almost all; while others, with a bright white surface, reflect nearly all; and the intervening degrees of brightness, with some modification from colour, correspond with the quantities of light absorbed—the darkest absorbing most, and the lightest reflecting most.

A pencil of light, in passing from the sun, proceeds in a straight line till it reaches the transparent atmosphere of our globe. With the exception of those rays that enter the atmosphere vertically the pencil is then bent aside, and continues bending round; the successive departures from the straight line depending on changes in the density of the air, and therefore gradually increasing from the outer limit of the atmosphere to the solid surface of the globe. This deflection, which takes place every time that light passes from one transparent medium to another, is called *refraction*, and produces a number of effects of great importance. Owing to this, the sun, stars, &c., are never seen in the places they actually occupy in relation to ourselves on the earth; for the ray that impinges on the atmosphere, and is bent there at a certain angle, comes to the eye as if from a different point to the real one. So also, when any object is seen through an atmosphere of varying density, or through glass or other transparent substance, all rays not entering perpendicular to the interfering substance are bent, and give a false idea of position. The nearer the sun, moon, or stars appear to be to the horizon, the more is the light refracted, and therefore the more false is the assumed position of the body. At the rising and setting of the heavenly bodies, there is thus the maximum variation from refraction.

All visible objects are so only from the fact that they either emit or reflect light; and as every part of a surface reflects according to the same law, a complete impression of form is transmitted through the eye to the mind. Where, however, either refraction or reflection is imperfect, and the form impressed is incompletely given, mistakes occur of the gravest kind.

Mirage.—Atmospheric illusions, connected with irregular and unusual refraction, are well known to occur in various parts of the world, and on various occasions. In the Scotch mountains, and on the Hartz, gigantic shadows have frequently been observed projected on mists or cloud, sometimes the reflection of the individual observing the phenomena, but not unfrequently enabling a person to see distinctly objects which, under ordinary circumstances, would be hidden either by the curvature of the earth or the intervention of a mountain. In the Polar seas, where causes of unequal refraction are

very common, ships have often been seen in the most extraordinary positions; and in the great desert, the false appearance of water and trees in the distance is frequent. Under the name *mirage* these singular phenomena have been often described. The *fata mor-*



ATMOSPHERIC ILLUSION.

gana, common enough on the coast of Sicily, is another singular example; and the atmospheric illusion represented above will enable the reader, not familiar with such facts, to judge of the nature and extent of the change produced.

Colour.—A pencil of white light proceeding from the sun is compound; being, in fact, a combination of rays of coloured light, heat rays, rays producing chemical action &c., in certain proportions which we need not here discuss. When light falls on some substances which have the power of absorbing colour-rays in a different proportion from that which makes whiteness, the reflected portion becomes tinted with colour; and if a ray is transmitted through glass, water, or other transparent substances, placed in certain positions, it is decomposed on emergence, presenting a line instead of a spot of light, and exhibiting colours if the image is received on a white surface. This coloured line is called the prismatic spectrum. A drop of water and a prism of glass perform the same operation in this respect, and when the eye is so placed as to receive the images from a number of drops at the same time, the result is a rainbow or halo, according to circumstances. The rainbow is then a result of the breaking up into their several parts of the rays of white light proceeding from the sun, each one being decomposed as it passes through a drop or vesicle of water formed in the air during a shower, and about to be precipitated in the form of a drop of rain.

It will then be easily understood that a rainbow is so only to the spectator, and that each spectator sees his own bow and no other. Occasionally a second bow is also seen at the same time, outside the first or principal one, formed by rays twice reflected

within other drops. This second bow has the colours reversed, and is fainter than the first, more light being lost by transmission and reflection. The natural order of colours, or that observed in the principal arch commencing nearest the earth, is from violet through the shades of blue to yellow, and thence through orange to the shades of red.

The rainbow is an arch depending for its completeness and magnitude on the altitude of the sun. When near the horizon there is nearly a semicircle, but often a part is wanting. When the observer is placed on rising ground, he may see more than a half circle, and if it were not for the interference of the earth a circle would be visible. In the case of waterfalls, and natural or artificial fountains, a coloured circular halo is not unfrequently seen. The interior of the bow is brighter than the rest of the sky.

Other effects of coloured light are seen in consequence of the absorption of certain rays while passing through a large quantity of atmosphere mixed with aqueous vapour. In the absence of much vapour, more yellow and red rays than blue are absorbed, and thus we have the clear sky showing a deep blue tint. As vapour is added, the blue becomes first gray, and then yellow, passing through orange tints to the deepest red, the blue rays first, and then the yellow being taken up, and nothing left but the red, when at early morning and sunset the bright light of the rising or setting sun passes through and is dimmed by a large quantity of atmospheric air.

The peculiar grayness that affects all lights, whatever be the quantity or colour, is well known to artists, and the cause of it—vapour in the air—should never be lost sight of. Distances require more and more gray as they recede, and positive colours of all kinds must be largely qualified with this sobering mantle, if they are to represent truly a natural object in its natural state.

Colour is communicated directly to various objects by the agency of the atmosphere, but it is also possessed by them naturally. Thus we not only have rocks of numerous tints of red, yellow, and blue, but they are often coloured by lichens, mosses, herbage, flowers, and trees; so that there is hardly a single shade that may not be matched in a landscape. The morning and evening lights passing, as has already been said, through many layers of air charged to a different extent with vapour, give all imaginable colours of yellow and red to the clouds, and mists on and near the horizon at no great elevation; while the light passing somewhat higher, having the blue and yellow rays abstracted, gives a clear rosy tint to the elevated summits of mountains. When these are covered with snow, the tint thus thrown and reflected becomes more delicate and exquisite that can be conceived, and the contrast afforded between the last rosy reflections from a snowy peak long after the sun has sunk beneath the horizon of the plains, and the cold silvery gray of moonlight succeeding it, is only to be understood by those who have wandered in mountain districts, where the climate is fine and the air pure.

Aurora Borealis.—Temperature greatly affects the state of the atmosphere in regard to light, both transmitted and reflected, and thus also modifies colour. But besides temperature, the electrical condition of the air assists in producing phenomena of great interest, especially in cold climates and high latitudes. Of this kind is the aurora borealis—an evidence of a peculiar kind of storm, during whose brilliant coruscations the electric equilibrium of the earth is restored. This phenomena is connected with the position of the magnetic poles of the earth, and takes place in the upper regions of the atmosphere, being frequently seen at the same time over a large extent of the northern hemisphere. A similar appearance has been observed near the south pole. Few artists have ventured to catch the evanescent and delicate tints displayed during this play of elements. They are equally difficult to connect and retain; and the

form in which the rays of coloured light appear, though often permanent for a considerable time, includes so much flashing, and such singularly shifting points, that there is little hope of retaining the accurate representation of any portion.

The following account of the aurora may, however, be useful, as it is accurate, and details the chief points in a magnetic storm. At the commencement, a white and luminous cloud appears in the direction of the magnetic pole, and remains there for hours in a stationary position. From time to time luminous waves and bright pencils of light spread themselves around the cloud, while bright scintillations and segments of circles more or less illuminated, appear and disappear successively at different points. Sometimes the light of the cloud is pale pink, but occasionally flame coloured, and the whole heavens present the appearance of a great fire blazing near the horizon.

Although the brightness of the aurora is often very considerable, the fixed stars may frequently be distinctly seen through it, showing that the intensity is small, and that it occurs in the higher regions of the atmosphere.

It lasts for many hours even in our latitudes, and further north is often almost incessant during the long winter nights.

The annexed Cut represents some of the ordinary appearances of an aurora, as seen

AURORA BOREALIS—LOCHLEVEN.

in Scotland, where it frequently occurs, and is often extremely brilliant. In high northern and southern latitudes, the effects, as has been described, are often even more remarkable, especially in the vicinity of packed ice,

where the coruscations are sometimes so brilliant and of such extraordinary varieties of distinct colour, as utterly to exceed anything in our own islands. Very curious modifications of the auroral arch have been observed, and it even appears that some districts are now more frequently subject to these magnetic storms than they were in former times.

Clouds.—Clouds are phenomena far more stationary and more easily studied. They consist, however, only of certain portions of the vapour present in the air, rendered visible frequently by the contact of two atmospheric currents in different conditions as to temperature and electricity, and constantly being destroyed and replaced, even when apparently remaining unchanged. Light fleecy clouds, in the higher parts of the atmosphere, are no doubt immediately connected with electrical changes, and may be independent of temperature, and have nothing to do with rain; but others nearer the earth are more easily traceable, and more permanent.

Clouds are of various kinds, existing in very different parts of the atmosphere, produced and modified in various ways, exhibiting distinct modes of grouping, colour, and form, and requiring to be studied, not only in themselves, but with reference to the states of the atmosphere in which each kind prevails. The highest are those already referred to as probably connected with electrical changes in the higher portions of the air. They are technically called *cirrus*, and vary in form and elevation rapidly and repeatedly. Long hair-like streaks of broken threads; spreading out in fan-like form, as if from a centre; or small lumps of curly vapour, dotted like fleeces of cotton over the sky;—they assume an infinity of shapes, and are common in the finest weather in our latitudes, being known by various names, such as mare's tail, mackarel sky, &c., which the fancies of the poet or the sailor have given. It is often difficult to determine their

PARHELION.

elevation, as they range far above the tops even of the loftiest mountains; but they have been calculated as occurring at least four miles above the surface of the land in some parts of Germany.

In these fleecy vapours, often perhaps snowy even in the greatest heats of summer, owing to their great altitude, are formed those halos and parhelia, or false suns, which are occasionally observed; and these are doubtless due to the refraction of the light through frozen particles.

Parhelia.—The following account of a remarkable phenomenon of this kind is from the "Philosophical Transactions of 1733," and is illustrated in the Cut in the preceding page. It is by Whiston, who says, "About 10 o'clock, A.M., Oct. 22, 1721, being at Lyndon, in the county of Rutland, after an aurora borealis the night before, wind W.S.W., I saw an attempt towards two mock suns. About half or three quarters of an hour after I found the appearance complete, when two plain parhelia, or mock suns, appeared tolerably bright and distinct, and that in the usual places—namely, in the two intersections of a strong and large portion of a halo. The mock suns were evidently red towards the sun, but pale or whitish at the opposite sides, as was the halo also. Looking upward, we saw an arc of a curiously inverted rainbow. This arc was as distinct in its colours as the common rainbow, and of the same breadth."

Varieties of Clouds.—When the cirrus clouds are abundant, they often precede at short intervals a change of weather. They then, in consequence of altered temperature, and the meeting of currents of air in different meteorological conditions, pass into streaky bands more adherent in appearance than the cirrus, and obscuring the light of the sun. The atmosphere near them becomes white; and if at the horizon, strong bands of dense vapoury clouds replace the light fleece. These are called *cirro-stratus* clouds. Occasionally the light small ragged and fleecy portions in the upper air become apparently more compact, and resemble balls of rather loose cotton, several cumulating together, but not obscuring to any extent the light of the sun or moon, which are readily seen through them, surrounded with a corona. This is *cirro-cumulus*.

The streaky character of the cirrus is often observed in what seems to be a peculiar modification, the clouds appearing to diverge from a point in the horizon, widening and spreading out towards the zenith, and again collecting towards a point in the horizon diametrically opposite the first. This is, however, an optical illusion; the clouds really existing in parallel bands, and the collection into a point at the horizon being a simple effect of perspective. The points of the compass, towards which such clouds appear to converge, vary in different places near the equator; they are chiefly north and south, but in our climate and latitude they are more commonly tending towards north-east and south-west.

All these varieties of cloud appear to pass into the *cumulus*, which are much lower and more distinct in form, and often accumulate during warm weather in the heat of the day, by the passage upwards of currents of heated moist air meeting the cooler air of the higher regions. Towards night the currents cease to rise, the air clears, and the clouds may disappear. But this is not always the case, as they sometimes continue to rise, and passing first into the state of cirro cumulus terminate in cirri.

It is the cirrus and cumulus clouds that chiefly deserve the careful study of the artist. They present the most fantastical forms. Their colour, though sometimes a dull gray, is often of the most brilliant white, and they take rosy and other tints from the rising or setting sun. Their shape is heaped and massive, feathery, or curl-like—grand, beautiful, or pretty, as the circumstances of the moment may determine. They

vary in height, from one to four or five miles, and in magnitude from the thinnest and smallest visible form of vapour to masses nearly a thousand yards in thickness.

The other clouds are called *nimbus*, or rain clouds; and though occasionally fine in their commencement they rarely long retain this character, but pass rapidly into mist, and present only a uniform monotonous veil of vapour.

The effect of clouds on the distribution of light in the atmosphere, and conversely the effect of light on clouds, are matters very important to the artist. Clouds often transmit red light, the other rays being absorbed by the vapour contained; but the same masses of vapour reflect white or coloured light, according to various circumstances little understood. The larger and more massive clouds reflect light from all parts of their surface, and thus one greatly modifies the appearance of another in a manner constantly changing with the relative positions of the cloud and the sun.

It rarely happens that clouds, however thick, are not to a considerable extent transparent; but, as already observed, they transmit coloured light, and being of different density from the air they also produce a certain degree of refraction. Their edges are thinner than their centre, and often in a different state for acting on light. They often cover only a portion of the visible hemisphere, and generally consist of several very distinct layers affected by and affecting light in very different ways.

The eye receives the idea of colour, in ordinary cases, only when a ray of coloured light enters it. But another mode must be mentioned as scarcely less important, connected with the faculty of memory, by means of which the absent or complementary colours are presented to the mind, when by any cause the eye has become fatigued by any strong light, whether of white, positive colours, or black. Thus, after looking at a white object intensely, the eye, if removed, or even while continuing to regard the same object, relieves itself by substituting a black image, and the converse; if the object looked at were red, bluish green is the relief; if orange, blue; if true bright yellow, a deep indigo; and if green, a reddish violet; in all cases, the colours, which, if supplied, would make up white light. These are called the accidental colours belonging to the various distinct tints, and they affect our ideas in nature with respect to the colours of natural bodies, and also modify greatly the colours attributed to clouds. Thus, for example, the eye regarding steadily a mass of cloud, soon becomes fatigued; the accidental colour is then seen; so that often the whole impression to the mind is modified, and the same scene presents itself differently to different persons.

The actual colours of clouds then, as judged by the eye, and referred to by the artist, depend partly on the nature and quantity of the light they transmit, partly on the light reflected by them, partly on unequal absorption of the coloured pencils, and partly on the peculiar constitution of the eye of the observer.

Another result of clouds, and of lights transmitted or reflected by them, appears in the shadows produced in connection with these masses of vapour in the air. A shadow may arise in consequence, either of a considerable absorption of all rays, or a more rapid and complete absorption of some one or some group. In this latter way are produced coloured shadows; but these also are assisted greatly by the eye and its imperfect action, since the accidental colour presented to the mind is often mistaken for the real tint. Every one, looking steadily at a varied landscape, sees partly true and partly accidental colours, and probably no two persons see exactly the same.

Aerial Perspective.—It remains to consider the causes and physical principles of one or two matters intimately connected with the phenomena of light passing through the atmosphere. Aërial perspective, chiar' oscuro, and tone, are amongst the chief of

these. Every artist, even without knowing their exact meaning, feels and knows that such things exist—that he must realize them, and act upon them either by instinct or education. They are indeed essential to the representation of nature and the appreciation of art.

In the way of definition we may describe aërial perspective as involving such an expression and representation of space as to give the idea of distance, and the separation of interfering bodies that do not touch, by a proper treatment of the gray tints in the atmosphere. Tone is the relation of light and shade in reference to distance, and is given by a nice treatment of its illumination, while chiar' oscuro includes only that general arrangement of light and shade which is required to give a proper idea of real objects. It is not, however, for us to dwell here on the working out of the great principles involved in these three essentials of painting, but rather to recommend to the artist the due consideration of their meaning in reference to the principles above enunciated.

Form and Structure of the Earth.—The operations of the artist have reference to the representation of nature generally, and therefore include form and structure, as well as effects of light and shade, contrasts of colour, and peculiarities of atmospheric effect already noticed. It is indeed of the utmost importance that the landscape painter, more especially, should be aware, not only of the general fact that there is in nature a harmony of form arising from and connected with structure, but also that he should understand so much of the true principles of structure as may enable him to pursue his art with success, and represent nature with truth.

The earth may be considered as having the general outlines of its form derived from the great mass of underlying rocks, which we may therefore regard as the bony framework or skeleton. Clothing this framework, as the flesh conceals and covers the skeleton, is a mass of matter, originally obtained from the degradation and wearing down of the older and fundamental rock masses, and now exhibited generally as stratified and detrital material, retaining here and there the old form, and not unfrequently penetrated by the ruder and more angular projecting angles, but still characterized by more regularity and tameness. The external surface usually shows a yet farther softening, corresponding perhaps with the skin, as the stratified masses do with the muscle, and, when draped with vegetation, completing the development of form in the landscape.

In all cases, however, the true history of scenery is best determined by reference to the soil and the underlying hard rocks, if such can be traced. The natural forms of the resulting mass ought also to be compared with others occurring under known circumstances elsewhere. The causes that have acted to produce such effects have been already alluded to in speaking of geology, and will be readily understood, including, as they do, both aqueous and igneous forces constantly at work in various ways.

Different kinds of Scenery.—We may now proceed to consider something of the different kinds of scenery presented in various parts of the world, chiefly with a view to show how far form and structure are associated, and also how far, in some cases, there is really no apparent relation whatever. The Cut, page 143, represents a waste of loose sand covering with perfect uniformity all irregularities of surface. Such a condition has probably been produced by a slow deposit under water, and the subsequent slow upheaval of a large tract. The bed of a lake or sea may thus become transformed into a desert, and the result may be regarded as normal, and as the natural consequence of the wearing away of soft rocks by water, the spreading out of accumulated sand at

the sea bottom, and the subsequent slow and very gradual lifting up of extensive districts.

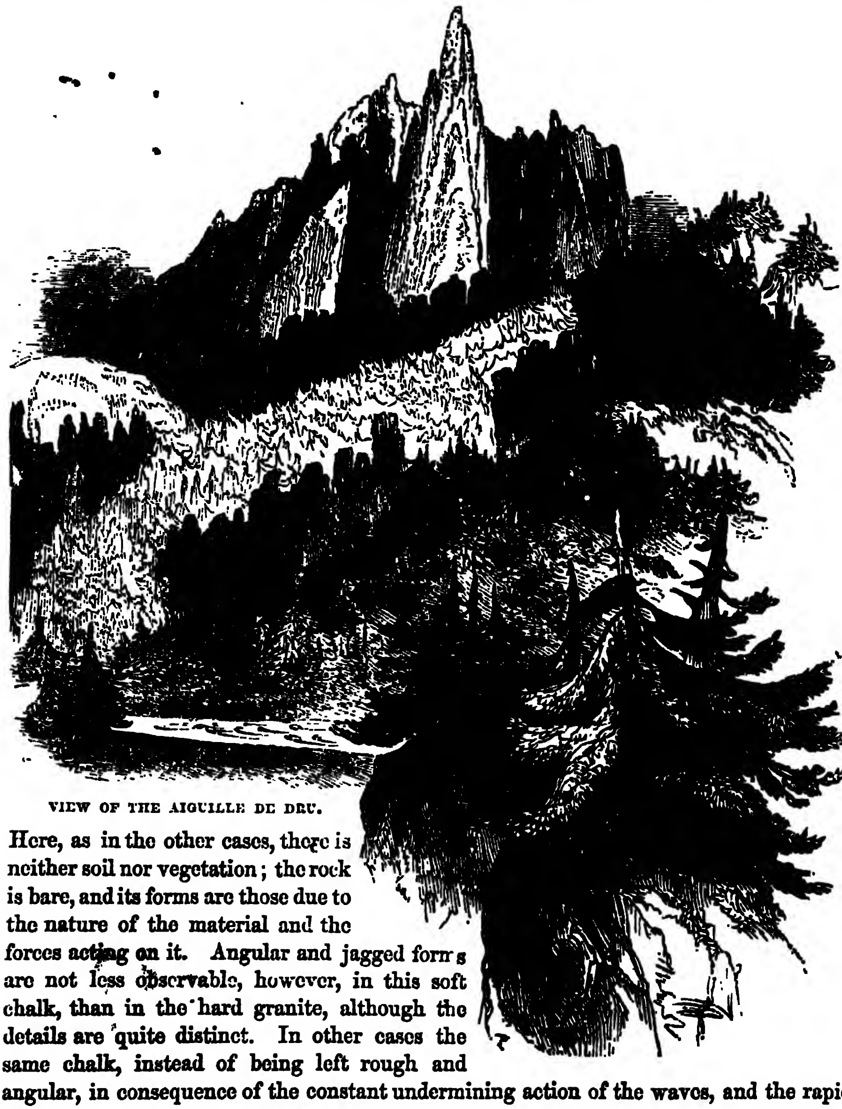
THE DESERT, WITH THE RUINS OF PALMYRA.

The contrast between this and some other kinds of scenery, in which the rock is hard, broken, metamorphosed, and greatly elevated, is often very striking in every respect. The one is flatness, and totally without character or form, possessing a certain amount of sublimity by its extent, but totally unpicturesque; the other may consist also of naked and abrupt rock; but the points and jagged ends may appear as if they had only recently been torn asunder, and projected into the upper air.

The spires, or needle-shaped detached rocks, called in Switzerland *aiguilles*, afford good illustration of this latter condition, and are seen to great perfection in the central mass of Alps near Mont Blanc. That represented in the Cut, page 144, "the Aiguille de Dru," is a singular and highly illustrative granitic mass. The aiguille is apparently isolated, and reaches to the height of 11,000 feet above the sea, the upper part forming one continuous shaft of more than 4000 feet, gradually tapering to a point. The sides are rounded, and the whole appears, as seen from a distance, to be composed of vertical plates of granite. It is perfectly inaccessible, and, next to the glaciers, is the most remarkable object in the valley of Chamouni. The view represents this shaft, with the Aiguille Vert behind it, the glacier de Bois descending into the valley, a continuation of the Mer de Glace, and the Arveyron flowing at the bottom. In this remarkable and singular instance, all the peculiar effects attributable to sudden disruption and excessive weathering are very strongly shown as affecting a hard rock, and may be contrasted with advantage with other angular and broken masses exposed to the action of the sea and air, and brought to their present condition in consequence of their extreme softness.

In the diagram next to be referred to (see p. 145), several portions of the chalk, a soft

rock of mechanical origin, have been worn and partly destroyed by the action of the sea.

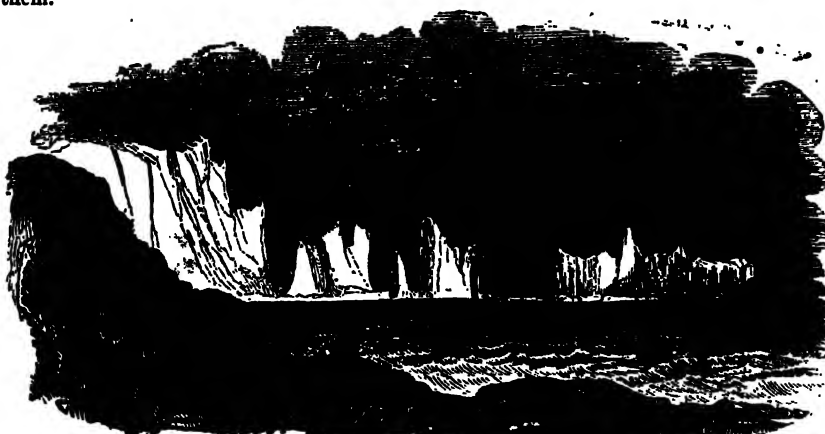


VIEW OF THE AIGUILLE DE DRU.

Here, as in the other cases, there is neither soil nor vegetation; the rock is bare, and its forms are those due to the nature of the material and the forces acting on it. Angular and jagged forms are not less observable, however, in this soft chalk, than in the hard granite, although the details are quite distinct. In other cases the same chalk, instead of being left rough and angular, in consequence of the constant undermining action of the waves, and the rapid destruction of the fallen masses, becomes rounded and altered by atmospheric influence. Thus the smooth coombs of Sussex and Devonshire are not less characteristic of limestone than the ragged peaks of the Alps.

These illustrations are intended to show contrasts of form, without reference to mineral composition or picturesque effect. Such varieties and contrasts are very common in nature, and always harmonize and agree in tone with the rocks to which they correspond; but they require great care in the artist to represent them without

exaggeration, and a certain amount of knowledge of various kinds to do full justice to them.



THE NEEDLE ROCKS, ISLE OF WIGHT.

Composition of Rocks.—It has been endeavoured to show, in the preceding pages, that the landscape painter should know something, not indeed of the details of physics or chemistry, but of the broad generalizations that have been obtained in those sciences, and of the laws that govern the internal structure and composition of mineral substances. So it is also with regard to the composition of rocks. Many of these contain portions, showing animal and vegetable remains in great abundance. The artist should appreciate the modes by which rocks are brought into the state in which he has to represent them, although he need not understand palæontology, or be able to speak learnedly concerning fossils.

A knowledge however, of minerals, their nature, mode of existence, ordinary combinations, and the modifications they may undergo, has to be learnt. The important ones are simple and few in number, as in a general sense almost the whole of those varied rocks, presented for observation and study over a large part of the earth, consist of mechanical admixtures of sand, limestone, and clay, only so far modified as to have their structure but not their form altered. Other rocks, such as granites, slates, and those cooled from igneous fusion, besides those of volcanic origin, also produce great effects in scenery. They form the salient points; and around or upon them the others are heaped.

Rocks exist in two conditions, either being simply aggregated masses, mechanically formed, or else similar masses so far altered as to have lost more or less completely the appearance of their mechanical origin. The result, in a picturesque view, is very different. Thus we see represented, in the above cut of the Needles, the appearance of a moderately soft rock (chalk), recently broken. The same mineral, when much harder, exhibits very different scenery; and, instead of being worn away altogether by the action of the sea, it resists that action, and forms a bold prominent headland. In the study of a rock, however, the effect can only be understood when the cause is appreciated; and thus it is not a mere question of whether sandstone, limestone, clay, or granite is present, but in what state these appear, and how far they have undergone metamorphic action.

The artist and the critic in art must therefore be educated to a certain extent in the

principles of Geology. He must know how, where, and when rocks of a certain nature change in appearance, and become cracked, rugged, rotten, or broken; how far a rock is crystalline, and owes its peculiarities to that condition, or naturally compact and hard, but not changed from its original state. Generally, indeed, position marks this, but not always; and the uniformity in composition of crystalline material, though far from invariable, is yet a characteristic worthy of notice.

As a further illustration of this part of the subject, I may refer to the great differences that exist between the rough, jagged, crystalline summits of many mountain chains (*e.g.* the Alps, as in the view of the Kandal Steig, page 129), the sharp and decided but perfectly distinct slaty (metamorphic) rocks on the flanks, the more regular and tilted mechanical rocks yet further from the central axis, and the alluvial flats of the adjacent valleys.

The crystalline rocks form hard, rough prominences that give the character to the whole—they are the rocks least easily destroyed, the most varied and irregular, and those most frequently occupying the highest places, because they appear to have been generally forced up from below.

Arrangement of Rocks.—Now there is, in all cases, a certain degree of order in nature with respect to the arrangement of rocks and their allocation, and also as to the way in which those differently metamorphosed are associated. All the limestones, sandstones, and clays were originally, no doubt, simple mechanical heaps of mud deposited or removed and arranged by water. These heaps becoming dry, and being acted on by various forces, being first, perhaps, sunk down to a great depth, and afterwards thrust up by violence, are now by no means the same in appearance as formerly; they retain, however, frequently their foliated or stratified character, as shown in the annexed diagram; and when examined on a large scale, are by no means so greatly contorted as is sometimes imagined by those who only study diagrams and a few striking exceptions. Such exceptions are important, and usually sufficiently picturesque.

KENT'S CAVE, NEAR TORQUAY.

Whilst the stratified mechanical rocks are thus usually regular, and often horizontal or inclined at a small angle, and occupy large tracts of flat or undulating land, the other series, of which granite is a well-known example, are essentially protruding rocks, having been forced through the rest, disturbing their horizontal stratification, squeezing into a smaller compass some portions, tilting others on end, and re-arranging them, as it were, in a new order. Thus, in a general way, when granites or crystalline rocks form the central axis, often concealed, but frequently approaching and touching the surface, they may be regarded as connected with the primary cause of movement. The semi-crystalline masses adjacent are again in strict relation to the granites, whether irregular, as gneiss and various schists, or presenting all the beautiful regularity of blue and green roofing slates. Of these, whether flanking others, or existing independently at the surface, the peculiar characteristics cannot be mistaken.

On the whole, then, the study of geology, as adapted to the artist, ought to make him understand, not only that there is an important difference in the appearance of objects having a different origin, but that the history of subsequent modifications is hardly less important than an account of their origin. It is not only the material, but what has been done with it, and how it behaved under certain changes. Position also, and the direction of stratification in stratified rocks, is equally desirable to be understood; for much of the true effect of rock scenery depends on these points, and the peculiar features of landscape in our own country may be everywhere traced to the same cause.

Position of certain Rocks.—The similarity of geological conditions over extensive portions of England, and the ready contrasts obtainable at small distances, are matters in themselves of considerable interest. Thus, if any one were to travel from Cornwall to Northumberland, he might, along the whole distance, find, either on his way or at no great distance, crystalline and metamorphic rocks of the same age, and in something of the same condition. The red sandstones, also, of Devonshire, are repeated in the midland counties and in Cheshire, and re-appear in Cumberland. The limestones of Bristol are found in Derbyshire and Northumberland, and the clays of the Dorsetshire coast differ in no respect from those of Oxfordshire, the Isle of Ely, and Lincolnshire.

We may even go a step further, and walk on the same chalk from Beechy Head to Salisbury Plain, and thence to Shakspere's Cliff; we may follow it through various counties into Cambridgeshire and Norfolk; we may find it again on the Yorkshire coast, and can then trace it across the ocean into Denmark on the north, and France towards the south. In all these cases the same rock is followed in the direction of its length and principal development. It may be observed in chalk-pits and other places, where the rock is exposed, that the lines marking the separation of different beds as deposited, are no longer horizontal, as they must have been originally, but show a decided inclination in some direction or other. The general direction of this slope, where the chalk ranges north-east and south-west along the surface, will be found to be south-east; but where the direction of the rock is east and west, the inclination is sometimes north, and sometimes south. This remark extends to the harder limestones occurring parallel to the chalk at some distance to the west, and also to the intervening clays and sands.

Mountain Chains.—The order of displacement, and the general system of elevation thus exhibited, lead us to a knowledge of some interesting facts concerning the mode in which mountains, hills, and valleys naturally occur. Thus, for example,

mountain chains may be considered to have reference invariably to systems of elevation, and this, whether the chains are lofty, as in the case of the Alps, Andes, Himalayas; or comparatively low, as in the British islands. In each case there is the peculiar character of mountain scenery, derived either from structure or elevation.

Hills.—Hills, on the other hand, are by no means always, though they are occasionally, structural phenomena; and thus, while mountain chains may be said in all cases to tell their own tale distinctly and at once, hills require especial study, and a reference to their origin, whether really owing to greater hardness than the surrounding material, or pushed up through that material, or simply elevated with the rest, and forming one of a series which, together, make up a ridge or rolling, broken ground.

Plains.—While the characteristic scenery of mountains and hills is generally due to what is called fundamental structure, consisting of some crystalline or altered rock thrust up from beneath, plains, on the other hand, are almost always formed by superimposed rocks deposited horizontally from water, and little tilted, though frequently elevated. Such plains exist, on a sufficiently large scale, in all parts of the world; sometimes almost level, but frequently undulating, or presenting broken surfaces of moderate extent but irregular form. They are sometimes nearly at the same level as the sea—sometimes, as in South America, in steps or terraces rising gradually towards the interior; and occasionally they form vast sweeps of table-land, several hundreds, or even thousands, of feet above the sea.

Physiognomy of Landscape Scenery.—It results from this mechanical condition and physical origin, that there is a vast difference, perfectly appreciable by the traveller, and not less so by the artist, in the different kinds of scenery presented in different countries. Plains, strange as it may seem, are as different in the impression they produce upon the mind, through the eye, as is the nature of the vegetation which covers them, or the climate under which they are seen. Mountains also have a peculiar physiognomy, dependent likewise on their origin. These latter are, as has been already remarked, indications of the skeleton subsequently clothed with aqueous deposits often masking the original form, softening the rough frame, and serving as a groundwork for the lighter drapery of vegetation.

The mountain, as the salient point, gives the outline which the artist must first seize. The peculiar characteristic of this form, whatever it may be, whether angular and serrated, or rounded,—whether deeply intersected and jagged, or smooth and monotonous,—the artist must carefully study. From this, as a starting point, he must watch the gradual changes that take place in passing to the valleys, the subordinate hills, and the spreading plains at their base. The annexed Cut (see page 149), showing the great plains of Languedoc, with a distant view of the Pyrenees, with some of the flanking ridges and the low hills that intervene, is a good illustration of this position, and one easily appreciated, especially by those who have visited similar scenery. For the most part, the plains extending across the south of France, in the valley of the Gironde, are sandy and extremely level, covered only occasionally, and near the coast, with any rich vegetation. Towards the Mediterranean there is a vast expanse of pasture land, and a good deal that is arable. On these pastures nothing interrupts the view for very many miles, till in the far distant horizon the gray wall of the Pyrenees rises amongst the mist and cloud, and presents a line so little broken by deep gorges, that one may often doubt, with some reason, whether the darker tint is due to the rising ground, or to a thicker mass of vapour.

In studying phenomena of this kind, and contrasting them with the soft undulating

scenery of our woodlands, or the bold but small proportions of English landscape, some idea is obtained of the actual meaning of the physiognomical character of a district.

VIEW OF THE PLAINS OF LANGUEDOC, WITH THE DISTANT PYRENEES.

This is the more marked when there is nothing essentially different to attract the eye, and remind it of the new object, although the general features are on a different scale. I have been much struck with this when standing on one of the higher points on the eastern side of the Alleghanies—first looking on one side across the sea of mountains there visible, and very imperfectly represented in the annexed Cut (see page 150), and then on the other to the vast plains of eastern Virginia, extending at my feet, and reaching to the Atlantic, with nothing more than slight and insignificant hills. The eye, it is true, can only take in a part, and often an extremely small part, of the wide extension that the mind comprehends; but no one can view and admire any kind of scenery without the exercise of the intellect producing its effect, and guiding the mind in the impression obtained.

In this case the impression was essentially that of vastness and wide extension, even when compared with equally beautiful scenery; and it is worth alluding to this, as helping to explain the cause of that idea of great magnitude which has often been spoken of by European travellers on first visiting the New World. Sentiments of the same kind, though less impressive, are felt on seeing the magnificent views from the Jura, across parts of France and Switzerland, or those of the great plains of Germany, from the Hartz mountains.

To the artist and lover of art, considerations of this kind are very important. If he catch these physiognomical relations, he may represent the scenery as it exists, and as it may be recognised; but if he neglect this study—if he be ignorant of the prin-

ciples, and his eye fail to catch that idea of the harmony of different parts which is essential to the true representation of nature,—he will not succeed in producing a picture which will give permanent satisfaction to any one whose taste is cultivated by the actual study of nature herself. It is right, however, to add, that an artist may obtain the required result without exactly knowing the successive stages through which his ideas

VIEW OF THE ALLEGHANY MOUNTAINS.

have been conveyed to him; although it can hardly be necessary to say that the knowledge of causes would be useful in the highest degree, and would often lead him to compositions of greater freedom and accuracy than he would otherwise dare to venture upon.

Alteration of Rocks.—Every country exhibits indications, though in very different ways, of change produced on the surface after the original deposits had been completed. Some of these have been effected by atmospheric action, spread over periods of almost indefinite extent. Elsewhere, especially in north temperate climates, the changes have been rapid, frequent, irregular, and very considerable.

Occasionally, also, they have been scarcely less considerable, but are due to very different causes—some decidedly aqueous, and others atmospheric.

It has already been shown, treating on the subject of Descriptive Geology, that almost all mechanically-formed rocks were deposited beneath the sea. In the act of being lifted up above the sea-level, towards their present position, they have been more or less worn while under the influence of the tidal wave; and it necessarily happens that the various kind of rocks have been very differently affected. Thus a soft rock, having a certain amount of tenacity, and of pretty uniform texture, has been scooped out into sweeps and rounded surfaces, well illustrated by the chalk coombs of Sussex, Surrey, and Dorsetshire. A rock also soft, but with less tenacity, such as

the sands and sandy marls common on many coasts and over wide tracts of country, presents a form altogether distinct; while hard sands, or hard compact rocks of other kinds, are also quite peculiar in their appearances. The singular scenery, in the valleys of some of the great American rivers running through vast plains, forms a good illustration of this peculiarity of character, and assists yet further to explain the striking difference which exists between America and European scenery, although the rocks really differ very little in any essential points. So again, in the interior of the country in Algeria, I have seen very peculiar scenery in a district where the rocks are of the age of our Gault, as developed near Folkstone or in Cambridgeshire; but the rock, *not* in itself very dissimilar, has been so greatly modified by the circumstances of elevation, as to have lost entirely its characteristic appearance, and to present an entirely new type.

As water never passes over land without producing some effect, either depositing or removing earth, or doing both at the same time, and as there are few parts of the world in which water does not occasionally make its way over the surface, so we must always look for such results, and even search for them if they are not manifest. There are, however, many positions where we should naturally look for greater results than elsewhere, and these depend partly on climate, and partly on geographical position.

In addition to the regular action of water on ordinary material, we occasionally see large accumulations of water-worn rocks, forming hills or irregular low hillocks. These are known in England under the name of gravel; but larger and more distinct heaps are called in Ireland *escars*, and similar heaps form hills of considerable magnitude in Sweden and Denmark. Under these circumstances they are distinct features, and must be regarded accordingly.

Importance of Studying Structure.—Thus, then, it is evident that the gigantic framework of rocks, which forms the skeleton of the earth, has a real and perceptible influence on its general outline, and even on the details presented to the careful observer of nature. And if, in order to draw correctly the human figure, it is desirable to be acquainted with the anatomy of the human frame, and study the hidden cause of those numerous prominences and projections which give character and expression when clothed with flesh, it is no less necessary that the landscape-painter should study the nature and conditions of rocks, their usual forms, possible modifications, and the way in which they are likely to be covered up, masked, or modified by atmospheric and aqueous action. It has been well said, by the author of "Modern Painters,"—"The laws of the organization of the earth are distinct and fixed as those of the animal frame,—simpler and broader, but equally authoritative and inviolable. Their results may be arrived at without knowledge of the interior mechanism; but, for that very reason, ignorance of them is the more disgraceful, and violation of them more unpardonable. They are in landscape the foundation of all other truths—the most necessary therefore, even if they were not in themselves attractive; but they are as beautiful as they are essential; and every abandonment of them by the artist must end in deformity, as it begins in falsehood."*

Characteristics of Limestone Scenery.—Let us now pass on to the consideration of scenery deriving its peculiar features from the presence of particular kinds of rock; and as limestones, sandstones, and clay, more or less altered, and alternating with each other, form the chief varieties of stratified material, these three subdivisions, with a fourth on granites, and other distinctly crystalline masses, and a fifth on volcanic rocks, will include all that require separate conideration.

* "Modern Painters," vol. i., p. 266.

In order to understand the nature and cause of the peculiar features of limestone scenery, it is necessary that the reader should consider the various ways in which calcareous rock is presented in nature in large masses. This is the more essential, as we

LIMESTONE MOUNTAINS ON THE COAST OF ARCADIA.

sometimes find it hard and crystalline, perfectly compact, but full of cracks and crevices; while elsewhere the same mineral is thinly bedded, brittle, and almost laminated. Occasionally we find it in bold escarpments, forming the numerous *scars* of Yorkshire* (Gordale Scar and Malham Cove being admirable examples), the crags of North Wales and Derbyshire, and the bold vertical cliff so common wherever similar limestone, or limestones in similar conditions, are developed near the surface. Again we turn to the chalk of the South of England, and find limestone equally pure scooped out into hollows by the action of water, and so soft that, except when preserved by vegetation, it is not only worn away into shreds by the action of the waves of the sea, but swept smooth by the rains of summer, and rendered rotten by the frosts of winter.

Limestone rocks often form mountain ranges, and constitute the essential features of the scenery, being elevated to the central and most elevated peaks; but they are more usually subordinate, and appear only flanking the igneous rocks. There are two ways, however, in which they may still retain the appearance and character of the main chain, since they may form escarpments facing each other, but at some distance apart, either when the interval is occupied entirely with rocks of much lower elevation, or when there is, between the escarpments, a continuous and lofty granitic or other

crystalline axis. The former is usually the case where the elevation has been moderate and slow, and the denuding action considerable. The latter is the case in the Alps, and elsewhere, when the elevation has been more abrupt and comparatively rapid, and is connected with a principal mountain chain.

Hardness.—It is by no means necessary that calcareous rock should be hard, to bring about either of the appearances above referred to; nor indeed, if now hard, is it at all to be assumed that the modifications of form to which it has been subjected were produced whilst in this state. Almost the softest condition, not merely of limestone but of any rock except blown sand, is that of common chalk, as developed in many parts of England; and the rounded lines, swelling surfaces, hollowed or rather scooped out coombs, and step-like terraces, so characteristic of it, are too well known to need more than a reference. These, however, are not confined to our soft chalk. They are equally characteristic of the much harder chalk of the valley of the Seine, and have even been observed in the hard limestones of the Caucasus, belonging to the same geological period. In this case the subsequent induration of the rock has not been accompanied or preceded by any destructive agency affecting its picturesque appearance, which remains the same as in its original soft condition.

The colour of limestone rocks requires study no less than the form, and indeed often bears a distinct relation to hardness and condition, as being affected by lichens and other dry vegetable matters on the surface. The actual colour of the rock varies from the most brilliant white, through all tints of gray to blue, being not unfrequently reddened or streaky from the presence of iron, and occasionally passing into brown, dark brown, and the deepest black, owing to the carbon or iron therein contained. The peculiarly rich and varied tints of marbles and crystalline limestones are rarely sufficiently seen, in the unpolished rock, to influence scenery; but there are many effects in limestone districts altogether peculiar, and not unconnected with the positive colour of the rock.

Hardness, frequently modifying form and colour, and greatly affecting the condition in which limestone occurs, is independent of geological age, and needs the special consideration of the artist in each district in which the rock in question prevails. Much depends on the nature and extent of weathering, something on the associated scenery, and not a little on the clearness or cloudiness of the atmosphere, in inducing the picturesque effects which form the artist's study. In all these, the element of hardness is extremely important.

Composition.—Limestones include carbonates of magnesia and lime, as well as pure carbonates of lime; and in some countries even carbonate of iron enters largely into the composition of calcareous rocks over extensive districts. In England, the dolomites, as the magnesian varieties are called, usually put on a yellow tint, and not unfrequently, as on the coast of Durham, exhibit remarkable forms, owing to the unequal and imperfect admixture of the minerals. In Derbyshire and Yorkshire they are more crystalline, and partake of the appearance of the semi-crystalline limestones; while in other districts they are easily recognised, owing to the irregular decomposition to which they are often subjected.

Carboniferous Limestone.—The carboniferous limestones, extremely characteristic of an important geological period, were formerly denominated, and are often still called, "mountain limestone," owing to their great development in the elevated districts of the West and North Ridings of Yorkshire, Durham, and Northumberland, the north of Derbyshire, and large parts of Lancashire. They are also seen in South Wales, near the Severn Valley, and in some parts of North Wales; and they occupy an

important part of the surface of Ireland. The delineation of this rock has been frequently and successfully attempted; but it seems difficult to avoid a certain amount of mannerism. The chief waterfalls of Yorkshire and Durham (extremely picturesque if not sufficiently large to be grand), the singular vertical cliffs called *scars*, and the wild precipitous and rugged masses often presented, are good illustrations of mountain limestone scenery; while Malham Cove, the cliff of Dinas Bran near Llangollen, the Derwent Valley near Matlock, the Chedder cliffs, and the banks of the Severn near Clifton, are equally characteristic and picturesque.

The High Peak of Derbyshire, and the narrow cleft-like valleys proceeding from it towards the south, afford a good example of the usual effects observable in hard limestone rocks in this climate. "Throughout the whole, the same general character prevails. A thin mossy verdure, often intermingled with gray barren rock, adorns the sides of the hills and the cliffs of the valleys, and occasionally the indestructible limestone rubble disfigures the steep acclivities, although even then a little brushwood occasionally enlivens and diversifies the otherwise sterile scene. The larger valleys possess, in an eminent degree, that variety of object, form, and colour which is essential to picturesque beauty, sometimes united with a magnitude of parts where grandeur and sublimity preside in solitary stillness.

"Travellers accustomed to well wooded and highly cultivated scenes only, have frequently expressed a feeling bordering on disgust at the bleak and barren appearance of the mountains in the Peak of Derbyshire; but to the man whose taste is unsophisticated by a fondness for artificial adornments, they possess superior interest, and impart more pleasing sensations. Remotely seen, they are often beautiful. Many of their forms, even when near, are decidedly good; and in distance the features of rudeness, by which they are occasionally marked, are softened down into general and harmonious masses. The graceful and long-continued outline which they present, the breadth of light and shadow that spreads over their extended surfaces, and the delightful colouring with which they are sometimes invested, never fail to attract the attention of the picturesque traveller. . . . . Such are the appearances that often occur amongst the mountains of Derbyshire. Descending into the dales, especially those through which the Derwent, the Dove, and the Wye meander, the eye is enchanted with brilliant streams, well cultivated meadows, luxuriant foliage, steep heathy hills and craggy rocks, which administer to the delight of the traveller, and alternately soothe or elevate his mind as he moves along.

"The broadest and the deepest valleys are in the highest parts of the Peak. The picturesque beauty of the valleys is increased by the frequently precipitous character of the hills or rocks which bound them. The faces of these rocks rise up almost perpendicularly from the sides of the valleys, as may be observed near Castleton, in the centre of the Peak, and near Stoney Middleton, in the valley of the Derwent, where the Castle Rock rises to a vast height, and obtains its name from the singular and turret-like form which its craggy projections and points assume. Matlock High Tor, and other rocks in Matlock Dale, and the rocks which skirt some parts of the valley of the Dove, are of this precipitous character. In the smaller and narrower dales the projections of one side have corresponding recesses on the other." *

The annexed Cut will give some idea of the nature and even of the beauty of this scenery. The valley is inclosed by high rocks; but here it opens out as if by some convulsion. In this dale the high eminences that form the lateral walls are often broken

* Rhodes' "Peak Scenery."

by projecting rocks assuming the most fantastic shapes—numerous sharp pinnacles and bold bluffs are seen on either side—while the stream that flows at the base often dashes over a bed of limestone pebbles fallen from above, and murmurs pleasantly along,

DOVE DALE, DERBYSHIRE.

relieving the gloom of the naked rocks, and at the same time tending to undermine them, and reproduce the angular and broken appearance that would otherwise soon be worn smooth. At the same time the wild flowers, common to hard limestone rocks, and the copses of mountain ash and other trees growing in similar positions, all combine to form a charming and beautiful landscape, not less worthy of remark in illustration of English scenery, than as affording a good instance of the peculiarities of limestone rock.

Besides these remarkable and highly picturesque limestones of Derbyshire, there are others equally picturesque, and of a somewhat different character, in the Mendip Hills, in Somersetshire. The Cheddar cliffs afford instances of the boldest features of this kind of scenery, and of the most picturesque combinations of wood with rock. Numerous chasms appear, often nearly vertical and extending throughout whole mountains, accompanied by some marked peculiarities derived from local conditions. The beds here are very distinct, and they are easily seen to have been lifted up much more on one side than on the other of these vast rents. It has been already observed, that the valley of the Meuse, near Namur, is another well marked example of similar conditions in rocks of the same age, producing similar results.

Ireland affords abundant examples of carboniferous limestone, but rarely on so grand and picturesque a scale as in England. Here, however, also, there are not wanting proofs of its tendency to the picturesque. Elsewhere in Europe there are few instances of its development, most of the limestones being of younger date.

Oolitic Limestone.—From the carboniferous limestone and dolomite, we pass on, in order of geological arrangement, to the marlstones of Cheltenham, and the oolitic series, as developed first in the neighbourhood of Bath, and then in its extension east-

wards, northwards, and southwards, throughout our island. The same rocks are far more extensively shown in the Alps and Jura mountains, in the south of France, in the north of Bavaria, and in numerous other parts of Central Europe. These countries include a great variety of scenery in which limestone is the essential element; and much of this scenery is of a character eminently picturesque.

The oolites, a group of limestone rocks running through England, from the coast of Dorsetshire to Scarborough in Yorkshire, are not less remarkable than the carboniferous limestones for a peculiar class of scenery, and equally deserve attention. The prevailing features are, however, much softer, the hills lower, and less abrupt—the valleys, if steep, less lofty, and the vegetable covering of a richer and more vivid green, and larger growth. The colour of the carboniferous limestone is generally a dark blue, passing into a dead black, while that of the oolites is usually pale gray, cream-colour, or dead grayish white. The liassic portion, indeed, is often blue; but this partakes rather of the character of a clay. The marlstone is of a creamy white.

The Cotteswolds, so called from the sheep-cotes abundantly dispersed over the wolds or hills of part of Gloucestershire, consist of a range of oolitic hills of moderate elevation, but traceable for nearly fifty miles, and presenting much interesting country both on the higher ground and in the inclosed valleys. A considerable variety of woodland and park-like scenery, of pleasing character, is met with in these districts; but there is little grandeur, and little that, independently of association, cultivation, and other accessories, would attract the artist.

Cretaceous Limestones.—The chalk downs, also, ranging through the country from the south coast to the Yorkshire cliffs, parallel to and at some distance from mountain limestone scars and the oolitic wolds, form a third feature in the limestone physiognomy of England. Jutting out in needles from the Isle of Wight and Flamborough Head, presented in fine bold cliffs as at Beachy Head, forming picturesque and lofty landmarks as at Shakspere's Cliff, or scooped out into large inland hollows as in the Devil's Punch Bowl, on the old Portsmouth road, the chalk is equally remarkable for boldness and softness, for colour, form, and vegetable covering. It rarely, indeed, exhibits much fine vegetation on the summits; but the hollows are often rich, and the general effect contributes largely to give to England that peculiar charm so strongly felt and so highly appreciated.

There are, also, some very strong and pleasing contrasts presented when this rock is undermined by the sea, bared by weather or by the hand of man, or so placed that it affords slopes too steep for much vegetation. In all these cases the bedded nature of the rock, its ready disintegration, and its white colour, combine to produce picturesque effects; while the mixture of sweeping and abrupt outline always marks the mechanical state of the material.

In addition to the usual white chalk of the south of England, there is a red variety of about the same hardness in Yorkshire, which somewhat alters the appearance of the mass when seen at a distance; and in other parts of Europe, nearly adjacent, as in some of the Danish islands, and on the banks of the Meuse, in Belgium (at Maestricht), a different texture and warmer tint also effect some changes.

Limestones of Continental Europe.—The characteristic points of limestone scenery, as dependent on geological date, are somewhat different in other parts of Europe, but still admit of comparison. The valley of the Meuse, near Namur, exhibits, in great variety and singular beauty, the scar or cliff-like nature of our mountain limestone in rocks of precisely the same age. The chalk of the north of France is identical

in appearance, though much harder, than the chalk of the North and South Downs; and in some other cases similar comparisons might be safely made. On the other hand, the grand and picturesque development of the oolites, as seen in the Alpine chain in the Jura mountains, in the deeply-intersected plateaux of southern France, and in those of Bavaria, are altogether different from that of the corresponding rocks with us.

Here, indeed, the mountain character is put on—the limestone is indurated, and often crystalline, and the projecting jagged edges shoot up into the clouds, rivalling the highest peaks of granite in the central axis.

We need, however, only travel a little further east to find, in the mountain range of the Caucasus, the very counterpart of the swelling downs of Sussex, Dorsetshire, and Wiltshire. The rock is hard, but the appearances are those of soft chalk, and the peculiarities of picturesque character are described as strictly analogous by the few travellers who have had an opportunity of judging.

Amongst the picturesque scenery of the softer limestones, the singular isolated rocks, well known as the Needles of the Isle of Wight, the coast of Normandy, and the coast of Yorkshire, have been already alluded to, and have been figured as illustrating the wearing action of the waves on such material. The Cut given in page 145 may be referred to as serving to give some idea of the result of such mechanical action under circumstances by no means remarkably favourable for its rapid progress.

PALMER'S CAIRNS, LUDLOW.

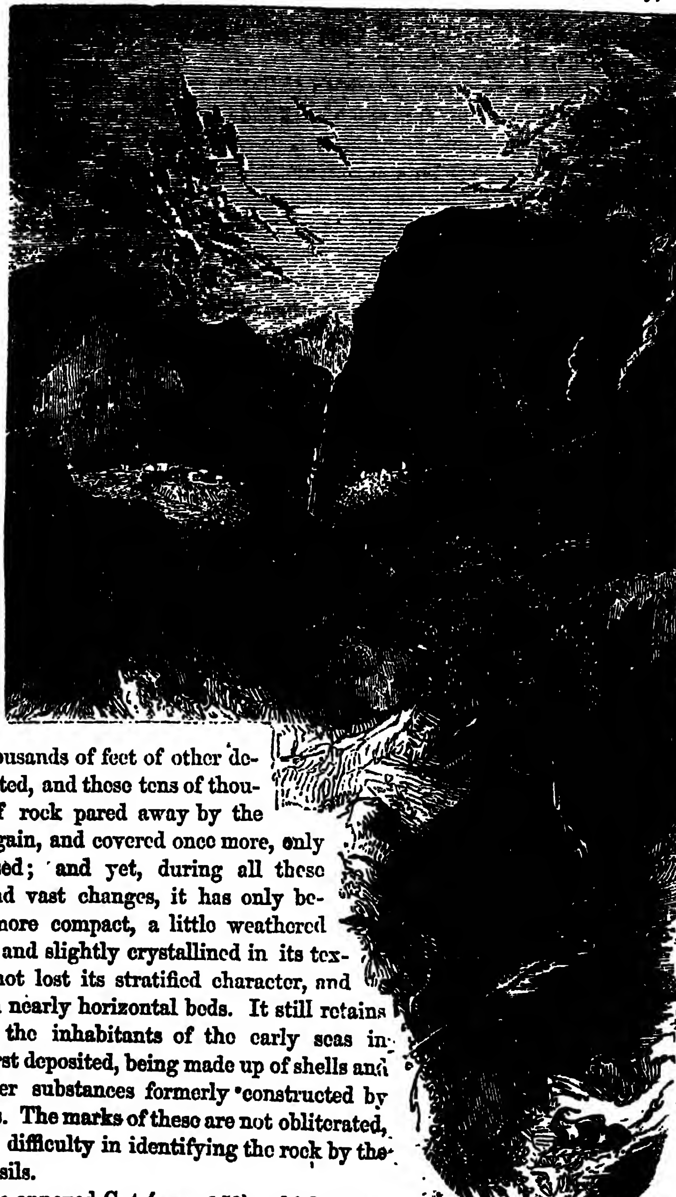
There are nowhere finer instances of the bold and picturesque varieties of limestone scenery—the rock being brittle, crystalline, and hard, and its position tilted, broken, and fragmentary, and placed far above the level of the plains—than those occurring in

the Alpine range, and especially in the extension eastwards of the main chain of the Alps. In crossing the great St. Bernard, the conical peak, called the "Sugar Loaf," is seen rising in the most romantic isolation. In the Col de Bonhomme, and in various parts of the valley of Aosta, other remarkable peaks occur; while the Salzburg mountains, flanking the central granite axis on the German side, and forming the Tyrol, afford numerous magnificent examples of all the peculiarities of form and colour that these rocks can assume. In Greece, again, the effects are equally grand and striking; but it is interesting to find, that as we advance in this direction the mountain limestone, or limestone which forms striking mountain masses, is gradually more and more modern in the date of its formation. Thus, while in England the so-called mountain limestone is of the carboniferous period, in the Alps, the limestones forming mountain masses are oolitic, and in Greece and the Caucasus cretaceous; while even tertiary limestones, and those, too, of no ancient date, are met with in the Mediterranean, on the north coast of Africa, and in the East, frowning precipitously above granites and other crystalline rocks, and occupying the front rank amongst the elements of picturesque scenery.

CAVERNS OF DUDLEY CASTLE.

Geological Age no Guide to Picturesque Condition.—Thus we see that mere geological age, except, indeed, in very limited districts, has no reference

to the nature or condition of rocks in a landscape. The Cut in page 157, illustrating the appearance and condition of the stratified limestones of Aymestry, Herefordshire, affords a fair example of one of the most ancient rocks of this kind, but little altered in relative position or appearance. It belongs to the silurian period, and has passed through all the changes and modifications of the west of England. It has been successively at the sea bottom, as the muddy bed of a former sea; elevated to form land; depressed to be covered up with tens of thousands of feet of other deposits; re-elevated, and those tens of thousands of feet of rock pared away by the waves; sunk again, and covered once more, only to be re-exposed; and yet, during all these long periods, and vast changes, it has only become a little more compact, a little weathered in appearance, and slightly crystallined in its texture. It has not lost its stratified character, and is to this day in nearly horizontal beds. It still retains the vestiges of the inhabitants of the early seas in which it was first deposited, being made up of shells and corals, and other substances formerly constructed by animated beings. The marks of these are not obliterated, and we have no difficulty in identifying the rock by the nature of its fossils.



SPRING ON MOUNT PARNASSUS.

So again, the annexed Cut (page 158), which represents caverns in the carboniferous limestone of Dudley, near Birmingham. These grand and gloomy caverns, partly natural, but enlarged and

rendered useful by art, have been excavated in a hard and compact but stratified rock, retaining throughout abundant indications of its origin in innumerable corals and many shells, to whose labours it may be said to be entirely due. Grand and gloomy effects of a peculiar kind are produced in this way, much dependent on the nature of the rock, and often confined to peculiar districts.

The contrast between these rocks, so distinctly traceable to a mechanical origin, and some others of much later date and of the same material, in which all traces of origin are lost, is very curious and important. The engraving to which the reader's attention is now directed (see page 159), represents bolder but equally characteristic limestone scenery of comparatively modern date, exhibited in the classic and picturesque mountain of Greece. The abrupt forms, and the deep clefts through which springs of water, or even sometimes ready-formed rivers proceed, are well marked in this and numerous other instances, and lend an additional and peculiar charm, and an available variety in those mountain tracts. A cascade rushes down the cleft, dashing its spray over the face of the rock, and producing that "dew of Castalie" spoken of by the poet. A hollow rocky basin, on the margin of the rill, at the foot of the cascade, and supplied by its own perennial spring, is supposed to be the fountain in which the ancient Pythia bathed, and whence she drew the inspiration which rendered the oracle so widely famed.

Recent Limestones of Coral Islands.—Reference has already been made to the peculiar agency of organic beings in constructing more or less completely some of the limestone rocks. In some parts of the world, where the labours of the existing coral animal are brought to light by the upheaval of the island basis on which they dwelt, we find odd and jagged piles of this material in a state throwing much light on the history of now compacted rocks, and not without a certain amount of quaint picturesqueness. The annexed diagrammatic view (see page 161) will serve to illustrate this condition. Many of the blocks represented are ten or twelve, and some twenty feet high, and they more resemble the temporary and irregular form of icebergs than the permanent condition of regularly constructed limestones. The following account of this curious appearance is given by Captain Wilkes in the United States' Exploring Expedition:—

"As far as our observation went, the upper portion of the island is composed of limestone or compact coral rocks; the cliff on its eastern side, where we first landed, appearing stratified horizontally in beds of ten to twelve feet thick, of a sort of conglomerate, composed of shells, corals, and pieces of compact rock, cemented together by a calcareous deposit. The under part of this bed had been much worn by the sea; the rich soil was composed of decayed vegetable matter and decomposed limestone, and the slabs that were lying loose on the surface had a clinky metallic sound when struck. The island has unequivocal marks of having been uplifted at different periods, the cliff at two different heights appearing to have suffered abrasion by the sea. Stalagmites were observed under the cliff, and also some stalactitic columns, fourteen feet high by six in diameter."

The account of this island throws so much light on the composition of the ancient limestones, and the causes of their peculiar features, that it is well worthy the attention of the careful student of nature. Many of the secondary and palæozoic rocks consist partially of coral banks, and others contain a large admixture of such material. In all these cases the analogy with the modern rocks of the kind here described is easily recognised.

Grottoes and Stalactites.—Mention is made, in the preceding notices, of a coral island of columns formed in the manner of those frequently found in natural caverns, and there called *stalactites*, or *stalagmites*, according as they drop from the roof, or rise from the floor. These sometimes, as in the great caverns of Antiparos, and those of Adelsberg, become subjects for the artist, and present the most grotesque, strange, beautiful, and

FORM OF BLOCKS OF CORAL.

even grand outlines. The following account of the Adelsberg caverns is sufficiently striking to deserve being quoted. It is from the pen of an American traveller:—

"We advanced with ease," he states, "through the windings of the cavern, which at times was so low as to oblige us to stoop, and at times so high that the roof was lost in the gloom. But everywhere the most wonderful varieties of stalactites and crystals met our admiring view. At one time we saw the guides lighting up some distant gallery, far above our heads, which had all the appearance of verandahs adorned with Gothic tracery. At another we came into what seemed the long-drawn aisles of a Gothic cathedral, brilliantly illuminated. The whimsical variety of forms surpasses all the powers of description. Here was a butcher's shop, which seemed to be hung with joints of meat; and there a throne, with a magnificent canopy. There was the appearance of a statue, with a bearded head, so perfect, that you could have thought it the work of a sculptor; and further on, toward the end of our walk, the figure of a warrior, with a helmet and coat of mail, and his arms crossed; of the illusion of which, with all my efforts, I could not possibly divest my mind. Two stalactites, descending close to each other, are called, in a German inscription over them, with sentimentality truly German, 'The union of two hearts.' The resemblance is certainly very striking. After passing 'the hearts,' we came to the 'ball-room.' It is customary for the inhabitants of Adelsberg, and the surrounding country, to come on Whit-Monday to this grotto, which is brilliantly illuminated, and the part called the ball-room is actually employed for that purpose by the peasantry. A gallery, very appositely formed by nature, serves the musicians for an orchestra, and wooden chandeliers are suspended from the vaulted roof. It is impossible for me to describe minutely all the wonderful varieties; the 'Fountains' seeming, as they fall, to be frozen into stone; the 'Graves,' with weeping willows waving over them; the 'Picture,' the 'Cannon,' the 'Confessional,' the 'Pulpit,' the 'Sausage-maker's Shop,' and the 'Prisons.' I must not omit mentioning one part which, though less grand than many others, is extremely curious. The stalactites have here formed themselves like folds of linen, and are so thin as to be transparent. Some are like shirt-ruffles, having a hem, and looking as if they were embroidered;

and there is one, called the 'Curtain,' which hangs exactly in natural folds like a white and pendent sheet. Everywhere you have the dripping as of a continual shower, showing that the mighty work is still going on, though the several stages of its progress are imperceptible. Our attention was so excited, that we had walked two hours without feeling the least fatigue, or being sensible of the passage of time. We had gone beyond the point where most travellers had stopped, and had been rewarded for it by seeing stalactites of undiminished whiteness, and crystals glittering, as the light shone upon them, like unnumbered diamonds."

It is true that these stalactites are local and unusual conditions of limestone, but they deserve some notice when treating of the picturesque features of the rock. Other modern limestones, almost equally grotesque, may be expected to exist wherever the material has been rapidly accumulated, and also when it has been quickly or extensively disturbed. Others, again, belonging to the tertiary period and of very late date, occupy evenly spread and little disturbed districts, almost as remarkable for monotony as the others for varied outline. In the south of Europe especially, there are wide tracts of tertiary limestone, presenting all the peculiarities hitherto noted—some being soft, and regularly bedded; others soft, but with no bedding manifest; some, on the other hand, are compact, hard, and durable, and these also occasionally show marks of stratification, although they are often without any such indications.

Crystalline Limestones.—It remains now only to speak of marbles, or crystalline limestones; but these, as far as they belong to the rocks whose age is known, have been already referred to, and if purely metamorphic, they will come under discussion in a future chapter. The latter hardly occur in England at all, as the only marble quarries—those of Derbyshire and Devonshire—are worked in beds of carboniferous or Devonian limestone. In Greece and Italy, where statuary marble exists, and in Ireland, whence small samples have been brought, the conditions in which the rock is found are such as to produce the scenery of metamorphic and not of stratified formations.

Colour and Vegetation of Limestones.—The colours of limestone have been alluded to as varying greatly under different kinds of exposure, and also according to the admixture of colouring matter in the rock. It may, however, be considered that white and gray, of lighter or darker tints, passing through very dark gray into black, are most likely to prevail, and are most natural.

The vegetation of calcareous rocks is also a subject of considerable interest, though the number of plants actually confined to particular minerals is very small. Orchids, in some districts—scented herbs in another; short, sweet grass in a third, mountain-ash, and many other beautiful trees elsewhere, vary and enrich the scenery, and produce the effects most striking to the eye of the traveller, and most sought for by the artist.

Conclusion.—In thus speaking at some length of the principal geological and geographical facts concerning limestone scenery, it may be noticed that we have scarcely gone beyond the simplest elements of art; considering only the expression of form, where it is of necessity striking, and where the representation of it is sure to be sought for. Incidentally, however, the study of rocks, with a view to their proper delineation, cannot fail to lead to an appreciation of those points of detail which the artist must especially consider, and which in our own country are rarely seen to greater perfection than in those districts where calcareous rocks prevail. In these will be found an amount of richness and variety, in respect of form, equal at least to anything met with in other rocks; and if colour is less perfectly exemplified, and vegetation less likely to

conceal the prevailing and characteristic outline, this affords only a stronger argument in favour of the usefulness of such studies. That they yield results in the highest degree satisfactory, the evidence already adduced, will, it is hoped, sufficiently show; and the sketches in the foregoing pages will illustrate the great and important principles which it has been our endeavour to explain.

But in delineating rocks of this kind, it is necessary to urge, above everything, the importance of not being influenced by any conventional notions of limestone or other rocks. The artist should go at once to nature, to study there all possible combinations of definite form belonging to the constitution of the rock itself, together with all those subsidiary and derived forms dependent on its decomposition and disintegration. However these may appear to contradict the prescribed and admitted outline, and however various the associated rocks may be, there will invariably be found a true harmony in all that nature does, and it is the comprehension and consequent expression of this which gives the highest and best finish to every work of art.

Sand Rocks.—We have next to treat of rocks in which the mineral called silex is a principal component part. Under this general definition must be included all varieties of sand, sandstone, flint, and quartz, wherever and however it exists; whether hard and compact, or of the loosest texture, and blown about by every wind—whether picturesque or monotonous—fertile or barren. The distribution of the mineral basis is so wide, and the actual proportion it bears to all the rest of the material of which the earth's crust is built up, so exceedingly large, that the danger and difficulty in describing its phenomena will arise rather from the almost universal presence of the substance in all forms, than from any statement of characteristic features which could not be illustrated by a fact.

Silica sand is widely if not universally diffused over the earth, and appears to have been so from a very early period of the earth's history. It is consolidated into a rock by many different cementing media, worn into shapes of almost every kind by the sea and air, hardened to every imaginable degree, and is alternately grotesque and grand, bold and tame, picturesque and desolate. It presents all shapes and all colours. It is naked, and clothed with the richest vegetation; pure, and mixed with every possible impurity; it takes at one time some eminently characteristic form, while at another it is masked by an admixture of limestone or clay to such an extent as to simulate their physiognomy. Occasionally it is rendered crystalline, and imitates closely the granites and porphyries in some of their most striking features.

Still the sand rocks are not without their own form and character, and they present in England and elsewhere many interesting and highly picturesque features. The loose sands of the sea shore lend occasionally the best assistance to form a middle distance, and produce great effects in marine subjects, but their very monotony and uniformity require the most careful study in drawing. The view of Lancaster sands, in the woodcut immediately before us (page 164), will remind the artist both of the difficulties and opportunities of such scenery; for in this case there is a wide estuary, which at low water forms an expanse of sand, only interrupted by the channel of the Lune. Beyond the flat sand, however, we here see a noble background of mountain scenery.

But sands associated with cliffs, and with all the varied effects of a sea coast, afford but imperfect ideas of the nature of sand scenery and its capabilities. The deserts of Africa and Arabia are much more marked, and are grand in their endless and hopeless monotony. In page 143 an engraving is given which may remind some persons of the essential peculiarities of such scenery; but it requires the genius

of a Turner to draw from such elements the materials of a great picture, and from the mere delineation of nature in her sternest and least smiling mood, to produce a vivid yet truthful image, bright with the warmest tints, and completely triumphant over the vast difficulties presented by the want of intermediate objects to mark the distance of the horizon, and show where the heated air meets the parched earth, and produces the difference in grayness that separates the moving sand below from the sand-cloud above. Many artists indeed have loved to attempt this difficult task, but it is too evident that few have succeeded.

In cases of this kind the sand is rarely coloured highly. There has been too much friction of the grains one on another, by the action of wind and waves, to allow of the superficial coating of metallic oxides being retained, and a slight tint of red barely

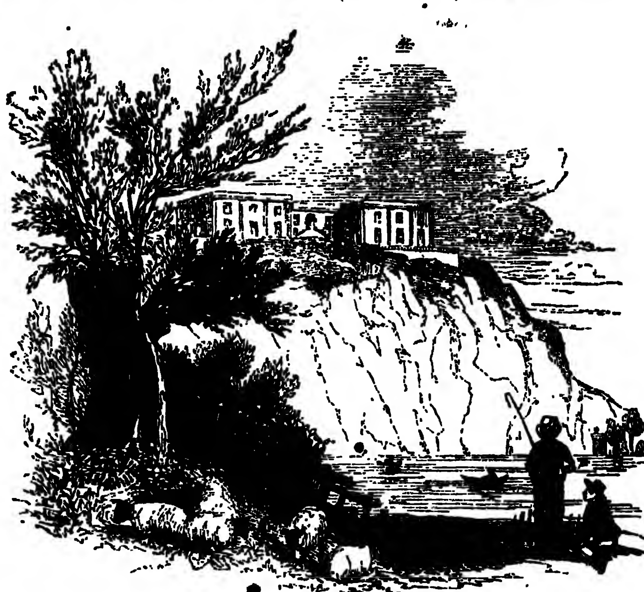
VIEW OF LANCASTER SANDS.

counteracts the natural grayness. Coloured sands, sometimes very brilliant, are not wanting in limited districts, but vast expanses of sand are usually tawny and uniform. Blown sands, occasionally forming low sweeping hills by the sea side, are peculiar and sometimes interesting objects for the artist, but have little positive colour.

Soft sands occur also in cliffs, and may then exhibit every variety of tint. The well-known example of Alum Bay, in the Isle of Wight, is too well known to require more than a reference, and similar phenomena on a different scale are not rare. It may, however, be suggested whether such appearances are desirable as studies; for although certainly natural, they almost always exhibit an artificial aspect, and are generally deficient in breadth and freedom.

Moderately hard sandstones, containing a larger or smaller admixture of clayey or calcareous matter, are both more common and more varied than those yet mentioned. They are of all geological periods, but each possesses some peculiarity. Thus the greensands (so called by geologists, owing to the occasional presence of green particles of silicate of iron) are well developed in various parts of the south of England and the Yorkshire coast, and afford scenery of remarkable picturesqueness. The Undercliff at the back of the Isle of Wight (some of the bolder and grander features of which, entirely

derived from the nature and position of the rock, are well known) has been frequently sketched. Black-gang Chine affords another example of stratified sand-rock of moderate and variable hardness. The cliffs at Hastings, those at Hythe, and others in the same district between that town and Folkstone—the fine and picturesque Leith Hill, the grotesque rocks at Tonbridge, and many other well known spots, have long since and frequently exercised the ingenuity of artists, and have served as the school whence some of our best landscape painters have obtained their experience and knowledge. Nor can there be better examples of varied colour, tone, texture, weathering, and vegetation to be found in rocks of the same degrees of hardness and composition. For many points they afford all that is wanted, and the artist studying them carefully may think he can become familiar with sand rock. To a certain extent only, however, is this true. There is a peculiar character by which rocks of the same age in the same country can often be identified, and in Nature there is always a harmony observable which depends on certain associations and peculiarities of mineral and geological condition, and is the same in kind over considerable distances of country similarly circumstanced. When, however, we compare greensand scenery with wealden—the Undercliff with Hastings cliffs and the Tunbridge rocks—a marked difference may be noted in colour, form, and vegetation, and each style of scenery is a study.



NOTTINGHAM CASTLE (*New Red Sandstone*)

The sketch of Nottingham Castle before us, introduces us to a district where there exists another kind of sandstone scenery—where the rock is soft, and in many respects not unlike that at Hastings; but yet where the result is very different in reality, owing to peculiarities of colour not seen in the engraving, but generally producing a distinctly red tint; whereas the others are greenish or gray. The effect of the colour is aided by the existence of marls not very common in the wealden rocks and greensands, and decomposing into a soil very favourable for vegetation; so that the districts in which the new red sandstone prevails are remarkable for the richness of their pasture land, as well as the beauty of the trees that grow there. The very fact of the presence of such different material as a component part of the rock, involves another result exemplified in the production of caverns, which takes place wherever water obtains access, and can un-

dermine any portion without bringing down the whole. Thus in the neighbourhood of Nottingham, and under the castle, such caverns exist, and are highly picturesque; the natural erosion of water having cleared away large open spaces, and left the harder parts supporting the roof as pillars. To see such phenomena in perfection, the artist must visit a singular district near Dresden, called the Saxon Switzerland, where they can be studied to great advantage. About eight miles above Dresden, on the Elbe, the valley closes in, the hills become more lofty and bare, and one of those natural barriers commences, which in many parts of the world mark some great geological fact in a manner equally grand and picturesque. For a considerable distance the river makes its way through narrow gorges deeply cut through a coarse grained sandstone, the inclosing rock rising in smooth vertical walls on each side. At frequent intervals there are similar lateral intersections, so that the whole mass is divided into isolated rocks, rising abruptly from a low level, and usually terminating in some grotesque or picturesque form. "Some have a huge rounded mass reclining on their summit, which appears scarcely broad enough to poise it; others have a more regular mass laid upon them, like the astragal of a Doric pillar; others assume the form of inverted pyramids, increasing in breadth as they shoot higher into the air. Occasionally they present a still more singular appearance; for, after tapering in a conical form to a certain elevation, they begin to dilate again as they rise higher, and thus assume the shape of an inverted truncated cone, resembling exactly, but on an infinitely greater scale, what often occurs in caverns, where the descending stalactite rests on an ascending stalagmite.

CAVERNS AT NOTTINGHAM CASTLE.

"The abyss,* which lies deep sunk behind the summit called the Bastei, though not so regular as some others, is the most wonderful of all, in the horrid boldness and fantastic forms of its rocks. The Ottawalder Grund is so narrow, and its walls are so lofty, that many parts of it can never have felt sunshine. I trode through the greater part of it on snow and ice, when all above was warm and cheery, and butterflies were sporting over its frozen bosom. Some small cascades were literally hanging 'frozen in their fall.' In one place the walls are not more than four feet asunder. Some huge blocks, in their course from the summit, have been jammed in between them, and form a natural roof, beneath which you must creep along, above the brook or planks, if the brook be small, or wading in water, if it be swollen; for the rivulet occupies the whole space between the walls in this narrow passage, which goes under the name of 'Hell.' When in one of these lanes you find an alley striking off on one side, and having

* From "Russel's Germany," p. 183.

squeezed your body through it, another similar lane, which you soon find crossed by another of the same sort, you might believe yourself traversing the rude model of some gigantic city, or visiting the ruined abode of the true *terræ filii*. Again, when from some elevated point you overlook the whole mass, and see these stiff bare rocks rising from the earth, manifesting, though now disjoined, that they once formed one body, you might think yourself gazing on the skeleton of a perishing world, all the softer parts of which have mouldered away, and left only the naked indestructible framework.

'The Bastey, or Bastion, is the name given to one of the largest masses which rise close by the river on the right bank. One narrow block, on the very summit, projects into the air. Perched on this—not *on*, but *beyond* the brink of the precipice—you command a prospect which, in its kind, is unique in Europe. You hover, on the pinnacle, at an elevation of more than eight hundred feet above the Elbe, which sweeps round the bottom of the precipice. Behind, and up along the river on the same bank, rise similar precipitous cliffs, cut and intersected like those already described. From the farther bank, the plain gradually elevates itself into an irregular amphitheatre, terminated by a lofty but rounded range of mountains. The striking feature is, that in the bosom of this amphitheatre, a plain of the most varied beauty, huge columnar hills start up at once from the ground, at great distances from each other, overlooking in lonely and solemn grandeur each its own portion of the domain. They are monuments which the Elbe has left standing to commemorate his triumph over their less hardy kindred. The most remarkable among them are the *Lilienstein* and *Königstein*, which tower, nearly in the centre of the picture, to a height of above twelve hundred feet above the level of the Elbe. They rise perpendicularly from a sloping base formed of *debris*, and now covered with natural wood. The access to the summit is so difficult that an Elector of Saxony and King of Poland thought the exploit which he performed, in scrambling to the top of the *Lilienstein*, deserving of being commemorated by an inscription. The access to the *Königstein* is artificial, for it has long been a fortress, and, from the strength of its situation, is still a virgin one. Besides these, the giants of the territory, the plain is studded with many other columnar eminences of the same general character, though on a small scale."

Very fine scenery, entirely due to the peculiarities of a sand rock which is extremely soft and readily acted on by all influences, is seen in the tertiary rocks of the south of Spain, between the Sierra Nevada and the coast. Here, owing to the remarkable dryness of the atmosphere and occasional very heavy rains which rapidly run off in torrents, the soft sands are usually left with walls absolutely vertical on one or both sides, and the openings, either into the rich transverse valley of the Alpujarras, or towards the yet richer and almost tropical vegetation towards the coast, afford the most striking contrasts with the pale gray mass of barren rock immediately before one. Rock of somewhat the same kind, but much harder, is seen at Shanklin chine in the Isle of Wight,—an interesting locality, well known to the English artist, and frequently sketched.

There is no limit to the number of familiar examples of soft sand-rock, varied almost always with occasional harder portions that have resisted somewhat longer the aqueous and atmospheric influences acting upon them. The heaths of our own country, and the pathless deserts of Africa, the grand but singular rocks of the Saxon Switzerland, whence may be seen the great expanse of the plains of Northern Europe, and the flanking hills of the Sierra Nevada, within sight of palms and plantains, do but afford

varieties of very similar mineral conditions modified by climate and by geological causes connected with elevation.

The induration of sand is a gradual process brought about sometimes by mere cohesion, sometimes by the infiltration of water containing iron, carbonate of lime, silica, or other substances in solution, and sometimes by a process of metamorphosis tending to produce a crystalline mass not unfrequently showing this tendency. Almost all true sand-rock, not yet changed into massive quartzite, presents some of the characteristics of a conglomerate, the grains of sand being of different degrees of fineness, often passing into small pebbles, and sometimes consisting of stones rounded or angular, of various dimensions from that of a pin's head to blocks of some hundreds of cubic feet. In the grits of all ages these differences occur, and in none more than those of the coal measures. Here, indeed, are found occasionally all the varieties and peculiarities of structure in this rock, and not unfrequently in a highly picturesque manner. The annexed representation of the millstone grit is one of numberless examples. It shows stratification and

MILLSTONE GRIT.

structure in the boldest manner, and admits of being referred to as a fair example of a very ordinary condition of the material.

Fine examples of the millstone grit occur in the neighbourhood of Sheffield, in Wharncliffe Park, and in other adjacent spots, where a certain amount of weathering has communicated that mixed character to the rock and that degree of decomposition which are favourable to the growth of vegetation, which accordingly spreads itself about, and gives life to the landscape.

With the exception of the deep red and greenish sands of the lower cretaceous series, and the paler tinted but still red rock, variegated with coloured marls, of the new red sandstone series, the prevailing colour of sandstones is gray, and this is almost always the tint retained on weathering. Laminated very frequently, especially when hard, uniform in appearance though really varied in texture, and usually very bare of vege-

tation when in any degree pure and free from marls, the sands are widely spread and well marked formations. They are found of all dates—tertiary, secondary, palæozoic, and metamorphic or crystalline; they are sometimes thickly bedded, and often occupy a large superficial range, but are occasionally in thin plates or bands almost vertical. Often much faulted, and subjected to the accident of fracture when a tough coherent mass was lifted far from its original position as a deposited sand, the different parts of a large series are also occasionally brought into comparison and contrast, and afford every opportunity for showing the varied action of climate and water.

Wherever this latter is the case, there exist all the elements of the picturesque in an artistic sense; but no valuable result will be obtained by the artist without preserving truth of detail; and this can only be secured by a knowledge of the causes and a study of the effect.

Sand-rock passes into quartzite,—the hardest and most crystalline form the massive rock can assume. This occurs sometimes only in veins and fragmentary masses, but

THE STIPER STONES.

occasionally on a much larger scale. Extensive masses of quartz rock are often extremely picturesque as objects in a distant landscape, but are usually too bare of all kinds of vegetation to be sufficient in themselves to complete a picturesque landscape. The stern

and gloomy grandeur of projecting masses of naked rock of this kind may be somewhat understood by the annexed sketch of the Stiper stones,—a remarkable instance well known to all who have crossed Shropshire. The woodcut, in preceding page, represents a view from the south end of the rocky ledge, whence a fine contrast is obtained between the rugged masses of quartz on the north side of a deep gorge through which the river Onny makes its way, and the rich woody lands of Linley watered by the same stream after it has passed the defile. These rocks are made up of a number of broken and serrated ledges jutting out to form the summits of the hills at heights varying from 1500 to 1600 feet above the sea. They exhibit stratification and joints, and are much faulted; the larger of the rugged isolated projecting fragments being from fifty to sixty feet high, and 120 or 130 feet in width. The slopes of the elevated moorlands through which they protrude, are covered with coarse detritus of the same rock, and many loose blocks have rolled down the ridge, chiefly on the eastern side.*

The old red sandstone exhibits a great variety of the best and most picturesque kinds of sandstone scenery. It is characteristically shown in parts of Herefordshire and South Wales; but its grandest development is on the shores of Scotland, where it wraps round quartz rock, gneiss and granite, and effectually resists the action of the waves on these exposed shores.

The rock is usually a conglomerate or coarse hard gravel, often of a dark red colour. Occasionally it forms detached pinnacles or needles, projecting beyond a coast line, as in some of the western islands of Scotland, or isolated from denudation although far inland. "I have often," says Hugh Miller, the historian of the old red sandstone of Scotland, "stood fronting the three Ross-shire hills at sunset in the fine summer evenings, when the clear light threw the shadows of their gigantic cone-like forms far over the lower tract, and lighted up the lines of their horizontal strata, till they showed like courses of masonry in a pyramid. They seem at such times as if coloured by the geologist, to distinguish them from the surrounding tract, and from the base on which they rest as on a common pedestal. The prevailing gneiss of the district reflects a cold bluish hue, here and there speckled with white, where the weathered and lichened crags of intermingled quartz rock jut out on the hill-sides from among the heath. The three huge pyramids, on the contrary, from the deep red of the stone, seem flaming in purple. There spreads all around a wild and desolate landscape of broken and shattered hills, separated by deep and gloomy ravines, that seem the rents and fissures of a planet in ruins, and that speak distinctly of a period of convulsion, when upheaving fires from the abyss, and ocean-currents above, had contended in sublime antagonism, the one slowly elevating the entire tract, the other grinding it down and sweeping it away." †

The character of the old red sandstone, and the way in which it is broken and worn away to form picturesque cliffs, is also well illustrated in some parts of the Irish coast. The Old Head of Kinsale, near Bandon in the south, is a fine example of this. A bold headland is here nearly separated from the mainland by the action of the waves, which have already worn away deep cavities beneath, and threaten soon to complete the destruction they have commenced. The dark frowning and gloomy masses of rock are piled one over another in an order not irregular, and the hugh step-like terraces, by which one may descend nearly to the water's edge, are admirable instances of stratification.

The vegetation on sand-rocks varies with the different circumstances of decomposi-

* See Murchison's "Silurian System," pp. 268 and 283.

† Miller's "Old Red Sandstone," 1841, p. 24.

tion and exposure, and the admixture there may be of foreign substances. Thus while the pure quartzite rises white, naked, and jagged above the ground, only covered with a few dry lichens, and unaffected by weather or atmospheric change, the more impure, though still hard and semicrystalline sandstones, in which iron and a little marl yet remain, are often partially coated with moss, ferns, and many other plants. Quartz veins, wherever occurring, are usually too pure and crystalline to admit of vegetation growing on them. They are thus often marked at the surface, and distinguished from the inclosing rock, while decomposing granites or porphyritic rocks, filling up fissures in quartz rocks, are not unfrequently marked by increased fertility. In the less compact but still hard sandstones and grits of various geological periods, where the presence of earthy or metallic impurities has altered the texture and colour of the rock, many trees readily plant themselves in the crevices; and it is only when we reach the other end of the scale, where are the loose moveable sands of white grains and considerable fineness, that we meet with that perfect aridity and barrenness which, however, must be regarded as characteristic of sand in its unmixed state.

Waterfalls often abound in sandstone districts; and no other rocks, perhaps, exhibit more of the peculiar features that belong to that kind of scenery. But it is usually where a certain admixture of material exists, as well as a different condition of the same material, that the grander phenomena of cascades usually occur. In England, the small but picturesque falls at Shanklin and Blackgang in the Isle of Wight afford good illustrations of this point; and others might easily be mentioned. Mixtures of wooded and water scenery, noble forests, soft rounded hills covered with vegetation; rich valleys, with the most luxuriant herbage; all of these are no less characteristic of some kinds of sand rock, than frowning jagged peaks, naked cliffs, or barren deserts are of other kinds. In one word, however, the difference may be explained; for wherever there is in the sand rock a sufficient admixture of clayey matter to make a soil, and wherever the rain occasionally falls to refresh the earth, there will be the refreshing green of vegetation; and where, on the other hand, the rock is crystalline or pure, or the rain does not fall, there will be a desert and a waste. The sands of Leith Hill, and other places in Surrey, the harder sandstones near Tunbridge, and the millstone grit of Derbyshire, are all examples of the former condition. The Stiper stones (see page 169), the dunes of the coast of Flanders, and the Sahara of Africa are instances of the latter.

In this account of the peculiarities of limestone and sandstone, the reader cannot have failed to perceive that, notwithstanding the frequent combinations that exist in nature, there is a well-marked physiognomy belonging to each, by which it may be recognised in a landscape. The mode of formation is not very different; but the weathering or decomposing on exposure, the effect of drying and induration, the degree of advance towards crystallisation, and the general grouping of vegetation on each, are things that may be recognised and delineated. It is certainly necessary to the truth of representation, that they should, in all their details, be familiar to the landscape artist; but this can only properly be done when he knows their origin and history.

Clay Rocks.—The physiognomy of clay rock in its various degrees of induration and weathering, involves perhaps quite as many and as well marked peculiarities as either of those already described. Like them it is sometimes hard and almost crystalline; but, unlike them, it is apt to form into a sort of pasty condition with water (which acts upon the softer varieties with singular rapidity); thus producing results altogether different from those where the material acted on is either thrown down by undermining, or worn merely by attrition.

Clay is too well known to need description. In its simple form, as mere argillaceous earth, it forms not merely the bottoms of valleys, but low cliffs, often vertical but constantly changing. It is mostly associated with tame and wooded scenery, and often forms the foreground in cultivated tracts. Most of the decomposed material of various kinds, from various rocks, ultimately becomes so far mixed up with argillaceous earth as to assume the distinctive characters of clay, and be regarded as belonging to this class of rock. It may readily be imagined, that in this state, easily and rapidly acted on by atmospheric changes of all kinds—sometimes washed away by rain—sometimes blown about by winds—at one season formed into a tenacious paste, at another hard and fissured by broad open crevices, the material in question will have to be regarded more as dependent on associations than as having of itself a distinct aspect.

The effect, however, of the earthy foreground of vegetable soil, and of clay rocks in this condition, is eminently favourable in most cases to the growth of plants, and is therefore one of the most important adjuncts to the beautiful in all landscapes. Limestone or sandstone alone, or associated, but without much clay, is comparatively barren, and wants the essential fertilizing principle. Clay, or argillaceous earth, gives this. It receives and retains water—it gives that mechanical support needed by the roots of plants. It contains, receives, and distributes better than anything else, the various chemical substances that are necessary or useful to plants, and whose presence or absence in many cases determines the existence of species; and finally, it combines and renders more useful various simple minerals, although itself an irregular compound of valuable miscellaneous substances.

It will be understood at once by the artist, and by every one who has a feeling for landscape, how important a study must that be which considers the principles of fore-

VIEW OF THE PLAINS OF THEBES.

ground, and the relations of earth and clay with hard rock. Thus one condition of clay is recognised, and this may be regarded as the simple and normal condition, little

altered from that in which it was originally deposited from suspension in water. When, however, this same substance has been long exposed to those influences which are constantly in action on the earth, a change supervenes, and the clay becomes more compact, harder, less affected by moisture, and assumes a tendency to split in certain directions much more readily than in others. In other words, it becomes crystalline, and tends to pass either into slate or claystone porphyry, according to circumstances of association with other minerals. Slate is the second condition of clay, and is altogether distinct from the first.

Even in its softest and most easily worn state, clay admits of the picturesque merely as a rock. Instances of this in England are rare, and of very temporary duration; but in the dry warm climates of the south of Europe and north of Africa, especially the latter, there are examples well worthy the attention of the artist. The nearest approach to them is seen in some parts of the Yorkshire coast, where, however, the hills are low, and the phenomena confined to the coast. Within the range of the Little Atlas, and about sixty miles in the interior from Algiers, is a scene of this kind singularly striking. There is here a wide extent of broken ground between and amongst the elevated ridges of the mountain chain, and of this a large portion is occupied by tertiary marls and clays. These are loose in texture, and have been but little cultivated. In places there are large tracts where no cultivation appears to have been attempted, and where the ground is cut up into a number of pyramidal hills, each formed of a multitude of small similar hillocks. The channel that has been taken by each little stream of water during the rains of one season remains till the next, and the whole scene is a curious mixture of the picturesque and the desolate not easily described. Something of the same kind, connected with much grander but not much more lofty mountains, is seen in the south of Spain, at the back of the great Sierra Nevada, where soft clays form a sort of flanking range facing the Sierra de Gador.

WHITBY CLIFF AND ABBEY.

In plains, the peculiarities of clay are so varied, and so frequently represented, that it is hardly necessary to give an example near home. The annexed Cut (page 172), representing the plains of Thebes, is interesting as an example of muddy detritus brought down and accumulated within the last few hundred years, within which time the plain has actually increased in breadth by one half, while no less than seven feet of mud have been deposited. The element of the picturesque is not here connected with the mineral or its condition. In another illustration is represented a view of the abbey and cliff at

Whitby, where the bluff appearance is not due to the strength but the weakness of the material, and to the fact that the sea wears away the soft rock, and removes it at about the same rate. In this, and many similar cases, the effect of weathering is at first sight almost the same, on soft unresisting clays as it is on hard sandstones and granite; but a little consideration will show that this is only the case apparently, and that really the changes must be of very different nature and extent.

However this may be, the clays found in England, such as the London clay, the gault (seen near Folkestone), the Oxford and Kimmeridge clays (forming the fen districts of Huntingdonshire, Cambridgeshire, and Lincolnshire), the Lias (well shown at Lyme Regis, Dorsetshire, and Whitby, in sea cliffs and in various places in inland sections), and the soft shales of the coal measures, will all, or any of them, serve as illustrations of the rock.

Slate is a mineral identical with clay in its composition, but so different in appearance as to require special consideration. Its hardness and remarkable capacity of being split in parallel layers of any degree of thinness are among the first qualities to be noted. It is not capable of mixture with water, as clay is, and thus weathers in a manner altogether peculiar, changing indeed very little by ordinary exposure. While also, clays usually occupy valleys and low hills, slate forms great mountain masses, and is met with amongst metamorphic limestones and sandstones, granite, porphyry, and

VIEW OF SKIDDAW (*a slate mountain*).

quartz rock. It exhibits varieties of colour as well as form, and is remarkable for a peculiar blue tint, admirably shown both in Wales and Cumberland where slates abound.

Slates, like clays, are of all geological dates. In England, indeed, and the British

Islands, they are only met with amongst the older rocks, rising as mountains in some of the finest scenery of which our country can boast. Thus the round-backed Skiddaw (see annexed Cut), owes its form to the nature of its composition and the texture of the rock. In the Alps, however, and in other mountain chains, the case is different, and the slates are far more modern.

The steep cliffs of the Rhine, in some of the narrowest and most picturesque localities, afford remarkable illustrations of the nature of schists, which, after all, are but modifications of slate rock. The accompanying view of the Lurlei, a well-known spot to most travellers, may be useful in recalling a few characters of scenery not without great interest in itself, besides having real value as showing the result of that tendency to split which belongs to the hard rocks of this kind.

It would not be difficult to refer to other and very different scenes, were it necessary to show how varied is the detail, and at the same time how fixed the general character of the scenery that depends on the action of known laws of the composition and structure of rocks.

Few materials exhibit more interesting varieties of colour than those of which clay is the basis. We may say, as a broad generalization (subject to very numerous exceptions), that if white and gray are characteristic of limestones, red in the same way is a common tint of sandstones, and blue of clays. But clays take other colours, and are especially liable to be marked by vegetation. They are also certain to show a considerable variety of light and shade from the broken surface exposed in cliffs.


VIEW OF THE LURLEI ON THE RHINE.

While, however, clay cliffs are thus broken, and even jagged and rough, being usually freshly broken, the lower hillocks that have fallen down will, if not carried away by the sea, present a smooth aspect, and be covered with grass. Flanking hills, too, where this material is present, are necessarily smooth, and often tame. They nowhere rise out of the surface, but repose, often heavily enough as a dead weight upon it. As features, therefore, clay hills are subordinate and tame.

When thin seams of clay alternate with sandstone and limestone, and are exposed

to the action of the weather, the clay is the rock most readily removed by such action; but the removal of the clay necessarily produces the falling of the other bodies; so that, although in such case hard rock forms the largest part of a series, the presence of clay, which allows the water to remove the support of the overlying mass, produces the destruction of these same superincumbent masses. Thus are produced many waterfalls, and thus also such waterfalls assume their peculiar and picturesque features. This is the case with some of those in the north of England, but is most remarkably exemplified in the great falls of the Niagara, which are due to the undermining of portions of clay strata, which are removed more rapidly than the rock above. One of the peculiar characters of slate scenery arises from the sharp angular fracture which is to be observed in it, and the smallness of the separate portions. This is the contrary of what is noticed in unaltered clays, where there is breadth of tone and uniformity of character always to be observed. In slate, on the contrary, there is a minuteness in the separate portions which cannot be mistaken. In the case both of sea cliffs and quarries, wherever slate has been considerably worked, or much exposed, and where it is consequently worn by the action of the sea, there is often found a peculiar depth of colour; and generally in these cases a purple tint is the one that prevails, which is accompanied by a peculiar softness almost resembling the bloom seen on fruit. This is peculiar to slate and clay rocks, and is derived from the inherent softness of the material itself, although in the mass it may have become hardened. This most essential peculiarity ought never to be lost sight of in drawing rocks of the kind now under consideration. There is also a peculiarity of tone which ought to be represented.

As the masses of slate that are presented in quarries and cliffs are essentially angular in detail, so those masses of slate which are presented in mountains are essentially hard in the mass. This is especially seen in the slate mountains of Scotland; and it occurs also in Wales and in the principal mountains of Cumberland. The peculiar roundness on one side, and the angular shape on the other, is characteristic of the rock in either case. Where there are pools and lakes of water accompanying slate, we very often have exceedingly fine effects, and especially in those cases where the water falls in considerable masses over slate rock. The general features of a slate and clay district vary very much, owing to the irregular action of water; and this must always be the case, because water acting at different times of the year produces different effects. It is very seldom the case that slate rocks are without some appearance of vegetation, usually consisting of lichens, and very often in rocks of this kind there are little crevices and ledges allowing of larger plants to make their appearance. It is also not uncommon for slate rocks to have both quartz and limestone veins traversing them, and then, as the limestone decomposes, it mixes with the clay, and produces marl. The seeds of plants blown about by the winds, or deposited by birds, grow in these recesses, and even a tree sometimes appears splitting open the rock, and making a way for its roots. The consequence is the production of a peculiar association of rich vegetation, with otherwise wild scenery. This natural planting on slate adds to the picturesque character of the rock. It sometimes happens that schists and slates are associated with large quantities of silicious matter, forming a very hard but irregular mass; and when exposed to the action of the sea, this decomposes in a striking manner, producing very bold sea cliffs. This is the case on the coast of Ireland, and also on the coast of the Isle of Man, where Douglas Harbour shows very beautifully the form which such rock can assume. Numerous instances of the same kind, on the coast of Great Britain, could be easily given; but in one or two

cases the weathering and the action of the sea have been different. All these varieties of form are seen occasionally as characteristic of this particular kind of rock.

Although, then, it may have seemed that the peculiarities of a rock, so common as clay, were hardly sufficiently important to claim a lengthened notice, yet it may be found that even in this apparently unimportant detail there are great truths in nature, and that if these are not observed by the artist, his picture will be imperfect, and unworthy of a high place among the efforts of the pencil.

But, indeed, of all matters that are important in a landscape pretending to high excellence, none are really more so than those that have reference to the subject now before us—the broken foreground of earth. The contrasting forms of distant and remarkable scenery are easily caught and preserved. The striking tints of colour, the bold masses of light and shade, the character of the scenery generally, (using this expression in its widest sense), may be obtained by the camera lucida or the daguerreotype, and thus all the more decided outlines be perfectly true. But then commences the work of the true artist; and it is only he who can first feel and appreciate, and then represent Nature's delicate detail of minute form and colour, who can be said to do justice to the scenery, and originate a true work of art. And here it is that knowledge and feeling of the nature of clay and earth, and the peculiarities of form they are likely to assume when acted on by air and water, come into full play. The more these details are attended to, the more near perfection will the picture be. "The higher the mind, it may be taken as an universal rule, the less it will scorn that which appears to be small and unimportant, and the rank of a painter may always be determined by observing how he uses, and with what amount of respect he views, the minutiæ of nature. Greatness of mind is not indeed shown by admitting small things, but by making small things great under its influence. He who can take no interest in what is small, will take false interest in what is great; he who cannot make a bank sublime, runs a chance of making a mountain ridiculous."

Crystalline and Igneous Rock.—We have now to consider those peculiarities of scenery due to the presence of rocks, either altered from their original mechanical condition, or formed directly by some igneous and crystalline action. These rocks are not unfrequently the central lofty peaks of great mountain chains, but they occur also in subsidiary ridges, in hills of moderate elevation, and even in wide plains. They are sometimes altogether barren, and occasionally clothed with the most luxuriant vegetation; in one place they astonish by their savage grandeur, in another fatigue by their tame monotony, and in a third charm by their beauty and softness. They include two very distinct kinds of material corresponding to difference of scenery.

Volcanic Rocks, Lava, and Basalt.—In various parts of the world there are, it is well known, certain conical mountains vomiting flame and smoke, and frequently belching forth showers of stones, or pouring melted rock on the earth's surface or beneath the water. These are called volcanoes, and in addition to those now in activity there are numerous others occupying whole districts where similar hills and rocks exist, not produced and not known to have erupted within the historic period. The annexed view of Cotopaxi, in the Andes of Quito, (p. 178), will remind the reader of the regularity of form which is peculiar to mountains having this origin. It is described by Humboldt as the most beautiful and regular of all the colossal summits of the Andes, being a perfect cone, covered with snow, and shining with dazzling splendour at sun-set. No rocks project through its icy mantle, except near the edge of the crater, and it is considered that the ascent to the summit is impossible, owing to deep ravines surrounding

the cone on all sides. The height of this summit is nearly 20,000 feet, and it is estimated that the fiery materials projected from it have been thrown into the air nearly 3000 feet above the top of the mountain.

VIEW OF THE VOLCANO OF COTOPAXI.

Without dwelling on the nature of volcanoes and their remarkable phenomena, it is clear that such scenery is of a totally different nature from any of those varieties hitherto considered. The Peak of Teneriffe, the fine cone of Mount Egmont, and the less considerable, but better known, appearances of Vesuvius and Etna, render it unnecessary to say more as to the general character of volcanic mountains.

Mount Egmont, however, is an example of what is called an extinct volcano, (p. 179). There is here, as in the active volcano of Cotopaxi, a cone of cinders and burnt rock; but the exterior cone is of hard lava, and there are no appearances of recent disturbance, although a still active volcano communicates with it by a ridge of hills.

One result of the peculiar origin of volcanic mountains is that, generally speaking, they show an exceedingly smooth shape, and want that terrace-shaped form which most mountain masses exhibit. If, for example, this volcano of New Zealand, or any other which exhibits strongly the characteristic appearance of such mountains, is contrasted with such appearances as are seen in the Alps, and have been frequently represented in these pages, a marked difference will be recognised, and the smoothness and regularity of the volcano will be seen to contrast well with the grand irregularity and picturesque roughness of the other kind.

Another point may be stated here with regard to these volcanic mountains. Generally speaking the cone consists of ashes, forming walls which have been often broken by torrents of lava, and sometimes by hot water pouring down the mountain side. Volcanic ashes contain, in many cases, the materials which in course of time and on decomposition become excellent vegetable soil. Thus the sides of a volcanic mountain will be covered with vegetation when it is below the level of perpetual snow, except where the ashes have been newly poured upon the surface. Wherever an irruption of ashes or a torrent of lava pours over the side of the mountain, there the vegetation would be destroyed, and there will be absolute barrenness; but wherever these ashes or the lava have remained for a long time, and the rocks have become decomposed, there will be an exceedingly fertile soil. Such wide contrasts of extreme fertility and extreme barrenness, are seen, for example, on Mount Etna, whose sides are alternately rugged and clothed with vegetation; while on the flanks of Vesuvius, on

the other hand, there is, in most parts, little relief from barrenness, owing to the rapidity with which the eruptions have succeeded each other. Whatever has grown is soon burnt up by the lava, and the lava has not remained sufficiently long to allow of its being decomposed, and a vegetable soil afterwards formed. These contrasts are peculiar to

VIEW OF MOUNT EGMONT, VOLCANIC CONE, NEW ZEALAND.

volcanoes, and are not found in rocks of other kinds. The colours of volcanic mountains are also peculiar. Generally speaking, the materials that have been erupted from them are of a dark or pale brown colour, consisting either of molten rock or ashes. In either case the colour is peculiar and quite different from the colour of ordinary rocks. The ashes, when seen at a distance, are, generally speaking, gray, having received that tint from being in a very minute state of subdivision; for all matter in minute subdivision is of a white colour. The volcanic rock, when in the form of fine ash, thus assumes more of the grayish tint, and this is probably really the secret of the colour alluded to. The only places in Europe where volcanoes are in a state of activity are the south of Italy and some of the Greek islands. There are, besides these, some islands off the coast of Africa, and the remarkable volcanic island of Iceland, off the northern coast.

But Europe is not without traces of volcanic action, in many other and widely distant localities. Thus we find crater-shaped hollows existing in places where there is no known volcanic action. In the neighbourhood of Cologne, an area of sixty or seventy miles in length, and almost as much in breadth, everywhere affords good proofs of volcanic action having gone on to a very great extent. This volcanic action is shown in various ways. The Siebengebirge, or Seven Hills, of which the Drachenfels

is the most striking, have been admired by every one who has travelled along the Rhine; but those who leave the river, and enter the country, will there see much more striking appearances, some of them remarkably characteristic of volcanic action. Some, indeed, of the hills near the Drachenfels are perhaps more easily seen to be the result of volcanic action than that is; but all are really constructed of volcanic materials. They consist either of lava, in one shape or other, or of volcanic ashes. In some cases the lava itself is seen where it has burst through the sides of volcanic hills, and its course may then be traced very distinctly. Some of the currents are even traceable on the other side of the Rhine; and throughout the whole of this district there is a remarkable continuity of structure, and one which evidently pervades the whole district, marking with characteristic features the existence of these volcanoes. On the left bank of the Rhine, where the volcanoes are not so well known to travellers, although equally familiar to the geologist, there are other striking evidences of volcanic action, consisting even of volcanic cones, from whose sides lava currents have been poured forth, and now remain. Throughout the whole district the soil is made up of volcanic ash, and there is no doubt that the volcanic products formerly covered the whole surface.

EXTINCT VOLCANO, CATAKECAUMENE.

Other districts are equally well known, though not perhaps equally familiar, in which extinct volcanoes are traceable. Thus, in the middle of France, in the Auvergne district, and again in Catalonia, similar phenomena are traceable, and are well worthy the attention of the artist, as presenting very picturesque features of a kind by no means so familiar as those of most of the scenes selected for landscape. Further east, in the now deserted countries of Asia Minor, the appearances are even more striking, and we there find large tracts of country burnt up and destroyed by ancient fires, though now no volcanic appearances are visible. The above view of the so-called Catakecaumene (the

burnt up district), is strikingly illustrative of this state. The following description is an admirable sketch of the class of scenery it refers to, from the pen of Mr. Hamilton:—

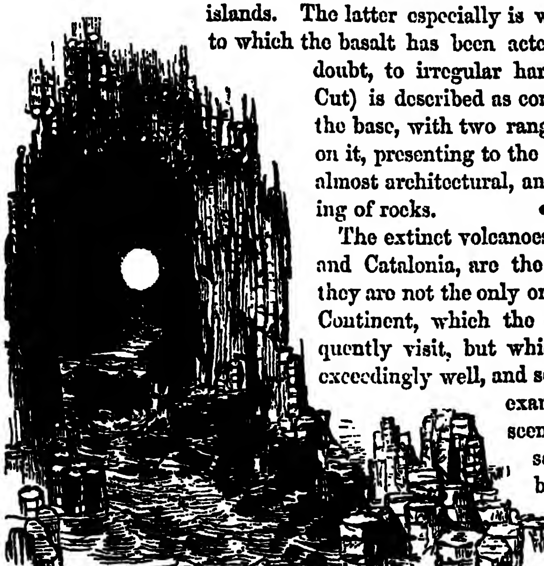
"Beginning with the north, on our extreme right was the barren termination of the ridge on which we stood, to the west of which a black and dome-shaped hill of scoriæ and ashes rose about five hundred feet above the plain. This was the Karedevlit, or Black Inkstand, the volcano of Koula, so near that none of the effects of its wild and rugged character were lost, and so steep, that to ascend its slope of cinders appeared impossible.

"In front of us, a black and rugged stream of lava extended from right to left, the surface of which, broken up into a thousand forms, looked like the breakers of a sea converted into stone amidst the fury of a gale, and forming, as it issued from the base of the cone, a striking contrast with the rich plain through which it seemed to flow. Beyond, to the north-west, were other volcanic cones, which, from their smooth and cultivated appearance, the vineyards reaching to their summits, must have belonged to a much older period. Farther to the left was the town of Koula itself, with its tall and graceful minarets rising above the lava."

It would appear, from historical documents, that the age of thirty centuries is at least due to the more recent cones, but the others are much older.

Other proofs of volcanic agency are not wanting; but the most striking and picturesque are those in which the lava, once poured forth in a fluid state, has since, in cooling, become columnar.

This peculiar and semi-crystalline appearance is well seen on the north coast of Ireland, and the opposite shores of Scotland and its islands. In these places, the mere mention of Giant's Causeway and Fingal's Cave, will at once call to the reader's mind the peculiar features of some of the most singular scenery in our islands. The latter especially is worthy of notice, for the extent to which the basalt has been acted on by the waves, owing, no doubt, to irregular hardness. The great cavern (see Cut) is described as consisting of a lava-like mass at the base, with two ranges of basaltic columns resting on it, presenting to the eye an appearance of regularity almost architectural, and supporting an irregular ceiling of rocks.


FINGAL'S CAVE, STAFFA.

The extinct volcanoes of the Rhine, Central France, and Catalonia, are the principal ones in Europe; but they are not the only ones. There are other parts of the Continent, which the English artist does not so frequently visit, but which exhibit this peculiar scenery exceedingly well, and sometimes very strongly. As an example, may be mentioned some scenery in the north of Bohemia—scenery that is partly volcanic, but that exhibits volcanic hills thrust through stratified rocks, and not merely consisting of ashes heaped on a plain. These hills are therefore distinct features, and they intervene between a range of country extending along the south of Saxony into the heart of

Bohemia. The surrounding scenery is of a totally different nature, and the phenomena in question have reference to the well-known hot springs of Töplitz, which are also the result of ancient volcanic action.

In Transylvania, again, there are a number of volcanic districts of this kind, all of them well marked, in which the volcanic passes into more distinct porphyritic structure; and there are many districts where it is difficult to trace the direct relation between the two. In these and other cases we have volcanic results without volcanoes, and frequently the material accumulated is spread in large tabular flat masses over a country producing that peculiar character of rock, called (from the Swedish word *treppa*, a stair) trap rock. Such rock is widely distributed in various parts of Europe and Asia, but most especially in India. A large district, including many thousands of square miles, in the north of the Indian peninsula, is entirely covered with rock of this kind, which is nothing more than lava of ancient date. In these cases it is probable the lava has been erupted below the sea, and there has been a great body of water, spreading this lava over a wide area, and forcing it to cool under a great pressure. The same thing is seen in central France; large bodies of lava have been poured out on the surface of these hills, and cooled in thin plates. This is the general character of basaltic platforms, and the transition of this form of basalt to true granite is not very distinctly made out, nor is it very important to trace.

Granite.—The appearance of granite is now to be considered. Granitic rocks are met with, generally occupying very distinct positions with regard to the limestones, sandstones, and clays, which have been already described. Granite must be considered as a central rock, forming mountain masses in the strictest sense of the word, and occupying the lowest place in point of geological position—the other rocks resting upon it. There are, however, two forms in which granite is presented to us. One form is that of a central ridge, round which, or on either side of which, other rocks make their appearance. This is the most common and best known form. The other is that of rounded masses, which are more or less decomposed. The first is a remarkable characteristic in almost all mountain districts, and in these cases the granite is presented to us as pyramids or wedges. In a few cases there is evidence of the rock having been erupted with violence, and the texture and nature of other rocks associated with it are altered to correspond in some measure with its structure. But the granite has more frequently undergone alteration itself; having, perhaps, in some cases been forced up slowly at a high temperature, gradually cooling as it is exposed. In cooling it has contracted, and contracting it has split; so that it is generally presented to us with a great number of angular forms. In some cases we have a central ridge, and on the sides of this ridge other rocks, often great masses of slate.

The appearance of granite itself is very well shown in some illustrations already given. Thus the Aiguille de Dru (page 144), and the view of the Kandal Steig (page 129), represent distinct views of the main ridge and the central part of Mount Blanc, and shew very well its striking angular form. This mountain is very lofty, and is placed in such a latitude, that for a very considerable part of its height it is entirely covered with snow, which, while it adds to the picturesque effect, does not of course seriously affect the peculiar form. The details of the form are seen to differ according to the point of view; but the general effect is not much altered.

The peculiar characters of granite scenery are indeed worthy of notice, as being almost always found to prevail; so that, except in those instances in which granite has become greatly decomposed (and it sometimes decomposes very rapidly), the scenery is

always characterized by these points. In the first place the outline of the rock is clean and sharp, and all the fissures are seen with a clear and angular surface. The more accurately such rocks are examined, the more the evenness of clean sharp fissures, exhibiting distinct angles, may be recognised. There is no rounding, except where the rocks have been exposed to friction.

Where, however, the granite is, as in the Scotch mountains, greatly affected by the action of the atmosphere—where the changes of temperature are very considerable and rapid—a certain amount of rounding must necessarily take place, although the general features are preserved (see annexed view of Ben Lomond). One result of this preservation of the usual appearance and structure of the rock, is that all the shadows are also very sharp.

Granites, therefore, in almost all cases where they are presented in large masses, and where they have been much worn and weathered, not only afford a distinct and clear outline of rock, but the shadows thrown are also distinct and clear, and this is a point which should always be attended to in representing such masses, as in a general way it may be said that decision of outline is the great character of granite scenery. There is, however, another point as to this scenery in the distinct elevation of the peaks. They rise boldly with great altitudes, and can only be seen distinctly in two ways. They cannot be looked upon to advantage from a near point as in an ordinary landscape,

WEATHERED GRANITE MOUNTAIN, BEN LOMOND—SEEN FROM THE LAKE.

and the observer should either stand near the rock and look up to them, as is the case in some parts of the Alps (see view of the Aiguille de Dru, already referred to), or look at them from a very great distance. The difference is considerable, and requires to be attended to. Standing near and looking up to a mountain, it is hardly possible to

obtain a clear and correct view of its essential features; the eye is not at all capable of appreciating the altitude, because there is nothing available for comparison. By the aid of the other senses one may obtain some appreciation of the magnitude of a mountain mass; as when watching a lofty but too near mountain side, a mass of snow is perceived falling which looks like a snowball thrown from the hand; but, after a considerable interval, the sound of an avalanche is heard, and is known to be the direct result of what has been seen; the ear and judgment here assisting the eye, a correct impression is obtained; but this, of course, cannot be represented by art. For this reason it is, that scarcely any attempts that have been made to present very lofty mountain scenery in detail, as seen from very near points, have succeeded. Mountain masses are thus usually represented from a distance, and they are best so represented, for it is only then that the true characteristics of the mountain are appreciated. In standing at a great distance, and looking at the mountain mass, the summits will be clear and distinct; the higher the point, the clearer, and yet the fainter, it will be. There will be no indecision in the outline of the mountain; but, on the contrary, it will be a distinct and sharp line; and indeed it is not possible for art to draw a line more sharply than nature represents distances in this way. The clearness and faintness of the general outline is softened by the peculiarity of the shadows; and the effect is almost transparent, because there is a great deal of mixed light thrown in the shadows. When a shadow, produced by a considerable mass of rock, is seen from a very great distance, so much light is mixed with the shadow that it cannot possibly be seen dark. The shadow will be as faint as it is possible for a shadow to be, and yet will be perfectly distinct.*

In speaking of the delineation of granite mountains there are some other facts worthy of notice. The first is that variety of form is the only thing that can enable the critic to understand the nature of the scenery and the structure of the rock; and another point to be referred to is the peculiar gray tint on such mountains when seen towards the evening. There is an effect about this latter phenomenon that no words can describe, although the pencil has frequently been found able to delineate it. There is, indeed, something in the effect of direct sunlight on these mountains, which is at once striking and peculiar, especially—perhaps exclusively—in Alpine scenery. On the western side of Switzerland, looking at the high Alps, the forms of the mountains are distinctly to be seen, and no doubt is suggested as to whether what is perceived is a mountain or a cloud, and yet the mountain and the cloud have, in such cases, as nearly the same tint of colour as it is possible to imagine; they are both nearly pure white, and the mountain is the more ghost-like of the two. It is an elevated mass carried away from the earth, but connected with it.

These are the principal points connected with the form of granite as it is represented to us in mountain masses. Granite is also represented to us occasionally in rounded masses and decomposed rocks, and is sometimes exceedingly picturesque. There are not many instances of this in England; as in Dartmoor and other Cornish moors the granite is little adapted for such representation as the artist requires. Still there is a character about it which marks it as belonging to this kind of rock. In other parts of the world decomposed granite exhibits other characteristics, sometimes very peculiar.

The clothing of granite with soil and vegetation is a point worthy of notice. There are two kinds of covering of granite: occasionally it is clothed and concealed by pic-

* See Ruskin's "Modern Painters."

turesque wood; but generally granite rocks are not favourable to vegetation, and we have many striking peculiarities arising from the absence of vegetation. Such rocks are, in fact, much more likely to be covered with snow than trees; and this snow-covering is remarkable in the mixture of lines that it gives; while the sweeping form given to snow by winds contrasts with the sharp and distinct shape of the rocks.

In the highest and most ideal consideration of this part of the subject, we must regard the granite mountains as indicating *action*, being, as they are, the rocky framework or skeleton of the earth, and exhibiting only repose when their forms are obscurely covered with rocks derived from them. Mountains are thus expressive of passion and strength; and the convulsive throes of nature, felt in the earthquake and seen in the torrent of liquid fire that issues from the volcano, are not less distinctly recognised in those far grander results which have lifted continents above the waves of the ocean, and which present themselves in the vast ridges and peaks of granite seen in the Alps and other chief mountain ranges on the globe.

Mountains rising simply and majestically above the earth are thus, as it were, the bones standing out from their fleshy covering. Masses of rock, of which a portion now lies buried thousands of feet below the general surface, and which position the rocks themselves once occupied, are seen springing up in vast wedges and pyramids, flinging away their covering of earth, and starting in fiery peaks above the clouds, as they bear aloft and exhibit to man the highest and the grandest representations of the majesty and the strength of nature.

It is thus a grand principle, that the mountains of igneous rock rise up from under all and are the support of all. On their flanks, the lower but yet considerable and often mountain masses of limestone and sandstone, and more frequently the slates, repose and incline, having been themselves lifted up, and therefore forming a subordinate group. The life, the vigour, the energy is communicated in proportion to the truth with which the central mass is delineated; and if this truth has not been sufficiently studied, and the picture has not the impress of reality upon it, nothing can redeem it from mediocrity. Since, then, here is the chief life, to this also should the attention be mainly directed; and it would be as reasonable to expect that a great artist should arise, who could paint the human figure and human flesh without a human being to study from, as that any one could truly represent a landscape, in which mountains are introduced, without having first studied in nature's life-school, and made himself familiar with the real as well as the conventional forms of natural objects. Everything is subordinate to the fundamental form of the solid earth; the form, whatever it be, is ultimately dependent on the elevation that has been produced, and this again has reference to the vicinity and magnitude of crystalline rock. The study, therefore, of crystalline rock, as exhibited in mountain scenery, cannot fail to repay the artist amply for the labour it may cost him.

Gravel and Boulders.—We have now to consider the case of rocks transported to a distance, and generally worn and rolled by mechanical attrition. This last portion naturally completes the whole subject to which attention has been directed, and it involves certain considerations, with regard to matters of detail, not yet alluded to. Whatever rocks may be composed of, they are sure to be covered, after a time, with debris, or fragments of their own substance that have been disintegrated, or broken up either by the action of the weather, or by water entering into the interstices, until at last there is a covering of vegetable soil. We may consider, then, that rocks, whatever they may be, provided they have been exposed a sufficient time, would

become covered up, first of all, with broken fragments of themselves and with vegetation; but it is also certain that, in addition to this, or before this has taken place, many rocks have become covered with fragments removed from a distance. Such rocks, of small size, accumulate to a great amount, and are frequently transported by water either by ordinary currents or by floods. In this way also are sometimes carried away larger blocks, which are afterwards deposited on the sea coasts, or at the sea bottom. This rolling of blocks of stone, from high mountains to a considerable distance, necessarily produces considerable effect on the edges of the rocks, and sometimes their edges are very much rounded; but this of course depends on the hardness of the rocks, and the facility with which it splits. Sometimes, instead of being rounded, the rock will be broken and jagged, and these are changes affected by peculiar and local circumstances. The different blocks accumulating at the bottom of the mountain form a sort of connecting link which unites the plains with the mountains. Such slopes are thus gradual ascents from the plain to the mountains, produced by a peculiar form of the mountains and the mode of its elevation, but consisting of material deposited afterwards. Hills, or low elevations of material deposited in the plains, do not arise from the plains, and always show this in their relation with the scenery. This grand distinction should be borne in mind, not only by the artist but by every person who interests himself with matters connected with art. It is important to remind the reader once more, that there are in this way two distinct classes of rocks, one class arising from beneath others, and forcing them up; the other class deposited on other rocks, and being mere heaps which rest upon them, and that these produce a considerable difference in picturesque effect. Mountains that rise from plains are generally jagged, sharp, and angular; they exhibit the appearance of life; whereas those hills that are merely formed by deposits resting on the surface are generally heavy, and do not add so much to the picturesque effect. The use of these hills may be considered to be rather with reference to the clothing of vegetation; the mountains are often most picturesque when they arise without any vegetation at all; but the hills are picturesque when they are covered with trees. We have then the scenery connected with boulders and gravel, connected with the hill scenery, because the hills are generally thus composed, and the characteristic of this scenery will be softness of outline. This almost necessarily belongs to the way in which the rocks have been formed.

Characteristics of Hills.—If, then, an outline is hard, it must be so for some good reasons. There must be large masses of rock, or mountain masses arising out of the surface. But these mountain masses do not depend on their height. They are seen as well when at a moderate as at an extreme height; there being, however, an apparent exception in the case of volcanoes, which sometimes rise from beneath the surface of the earth, and are not entirely formed of ashes poured upon the surface. A few examples will show this. A mountain chain exists in Wales; there are hills in Switzerland higher than the highest mountains in Wales, but they are not therefore mountains, nor are those in Wales hills. In the strict sense of the words, hills, consisting of isolated groups of boulders and gravel, belong to the subject of foreground; and the grand distinction between foreground and background, in principle, is that of hill and mountain. Hills, then, belong strictly to foreground, provided that the object of the picture has reference to the general structure, and not to any particular details. It will necessarily be the case that, where the object of the picture is to present details, the foreground may be any part of the hill, country, or plains; but, where the picture is intended to be comprehensive, and represent nature on a large scale, a background is

required connected with mountainous and not hilly features. The background determines the character of the picture, which the foreground modifies. In the latter case there is no sharpness of edge, although by the mode of wearing there is proof of considerable hardness. There is, however, great difference between this want of sharpness on the edge of the rocks, and want of hardness in substance, and this effect is produced by an artist when he understands what he is about, but is liable to be lost if some attention is not paid to the rock and its structure. With regard to transported rocks, local circumstances will very often explain the peculiarity of their appearance. The Logan stone in Cornwall, and the Gray wethers on Salisbury Common, are very good examples of this peculiar structure, and of the effect of rocks which have been removed to a distance, and which thus contrast very much with the general structure of the country in the neighbourhood.

Weathering of Rocks.—In consequence of the distance to which the rocks have been removed, and the difference of structure that they exhibit when placed in their new position, we very often have contrasts of colour, and in the nature of vegetation. Thus, if a block, or group of blocks of granite, is removed from a distance into a soil capable of growing plants, or if sandstone rocks are removed to a distance into a chalk or clay district, there is not only a considerable contrast, but, if such rocks be capable of disintegration, and of mixing with the soil, they produce a rich harvest of plants; but if this be not the case, either the transported or local rock may be covered by vegetation, while the other is barren. This is especially manifest in the case of the gray wethers in Salisbury Plain, already mentioned; for here the plains themselves are formed, for the most part, of chalk, and are covered with vegetation; but upon them are strewed hard masses of sand which do not disintegrate, and therefore do not allow of a growth of plants upon them. The result is the strongest contrast in colour and general appearance. The rocks are very much weathered, but still they do not harmonise entirely with the surrounding scenery; they form a contrast, and add in this way to the picturesque effect. Something of the same kind is seen at the back of the Isle of Wight, where, in consequence of the irregular action of the sea and the mixed structure of the cliffs, there is a considerable amount of wearing, and the rocks are constantly renewed.

There is often a good deal of interest in observing the condition of rocks in water, and the way in which rocks, removed by water, make their appearances. Such rocks are generally rounded and affected by the action of the water in a different way from those which are constantly rolled on one another; for, in the latter case, their form is more completely rounded than when they are brought to a stand-still at any particular point, and water is rushing past them. There are many instances in Wales where rocks have been brought down by water, until at last the mountain torrent widens out, and, when checked in its progress, deposits a very considerable part of its load. Rocks are thus accumulated in particular places, and when once there are seldom removed, particularly the larger ones, because it seldom happens that the current comes with sufficient force to set them in motion. The bed of a torrent may thus be choked up with large blocks, which then become acted on by water in a different way from before.

Grayness.—There are some interesting effects of light, with regard to foregrounds, which it is worth while next to notice. Amongst them is the want of grayness. Generally speaking, the further an object is from an observer, the more gray the light and tints will necessarily appear, because the effect of grayness is pro-

duced by the passage of light through a large quantity of air. The result is, that although the colour of an object may be quite as vivid or more vivid in the distance it will have a different tone of colour from a portion of the same object in the vicinity. The gray may be as bright at a distance as when near, but that part of the object which is near will be much less gray than at a distance. This is necessarily the result of the laws that govern light, and may be noticed by any one with respect to natural objects. The grayness of effect is a point frequently attended to by artists without their knowing the reason; but it is a point that is much better acted upon, if it be understood, than if merely performed by rule, without being thought of.

Vegetation.—When we consider the effects produced by close observance of Nature in this way, we shall often find many curious results of vegetation which at first might not present themselves. There is, for example, a very distinct reference to the structure of rocks in the kind of vegetation natural to them. Thus certain kinds of trees, in our own country, generally grow best on particular kinds of soil. At first this might seem to be an observation merely interesting for the agriculturist, but it ought not to be neglected by the artist. If an artist wished to represent a scene, in which a great amount of sand and sandstone prevailed, and desired to exhibit this in the most perfect manner, but were to place on each rock groups of trees which generally are confined to a different soil, he would produce a mixture of structure and vegetation which, although it might not strike the observer at first, would yet ultimately be found to injure the picture, and interfere with its general effect in a manner which would entirely prevent its ranking in the first class. This is a point well worthy of notice, although rarely acted upon by artists, and certainly not recognised by any of the old masters. Generally speaking, there is in Nature a harmony between the kinds of rock and the kind of trees that grow upon them; this is the case in all countries and in all climates. In England we find the oak and such like trees chiefly growing on clayey tenacious soils, and not on loose sand; and thus a landscape, with a group of fine oaks, in which the style of rock and its colouring should give the idea of loose sand, would be untrue and unnatural. So again, if we wish to represent firs and heath, it would be just as improper to represent the soil and rock as a clay; since, in fact, these are trees which grow best on sand, and when growing on rocks of another kind they would probably be stunted and unhealthy, and therefore should not be represented at all. The important point, however, to be observed is, that if such trees are introduced they should be so with strict reference to the structure of the country.

Conclusion.—Before altogether quitting this part of our subject—in which an endeavour has been made to bring forward, as an application of natural science, the consideration of many subjects not hitherto thought very important in the education of an artist, or at least not directly bearing on the practice of his art—it may be well to add a few words concerning the fear that some (both artists and critics) may entertain, lest the familiarity engendered by accurate knowledge of nature may chill and check the powers of the imagination, and deprive the artist of his chief inspiration, by removing the warm and deep impressions of the heart, and replacing them only by the feeble though more distinct outline appreciated by the intellect. We are often told that much of the beauty of great works of art, in every department, arises from the dim obscurity which magnifies real objects, and gives existence to shadowy and unreal forms. Such a view is honestly believed, as well as thoughtlessly said; and men of genius, whose influence is deservedly great, have advocated it; it is therefore more than probable that some of the readers of this article may think, or may be hereafter told, that ignorance

of natural things is the chief source of our admiration and feeling of the sublime. To this, however, it may be replied, that the true feeling of that which is great is but a reflection of the feeling of infinity which every study of Nature encourages and renders more powerful.

We may, however, safely and wisely appeal to other forms in which genius has shown itself; to the poet whose name is handed down from generation to generation with increasing love and admiration and worship, or to the great masters of music, who in a language that may be called universal have immortalised sounds which have a deep response in every human breast. Works of genius of all kinds are indeed, and always have been, and will be, admired and loved in proportion as they are clearly felt to be true in reference to human thought and human experience. It is not less exalting to the imagination that we now look, in the truth of astronomical science, to distant and unnumbered worlds—known only by the telescope—communicating to us no light and no heat—connected by no tie but that great law which pervades all matter—it is no less affecting to the imagination that we can measure the vast orb of the sun, and tell the history of distant worlds belonging to our system, but whose very existence the dry pursuit of mathematical science first teaches us—than it was when in the days of ignorance men in their fancy and imagination saw the planets and the stars nailed to their celestial vault, and when the ideas of men on such subjects were limited by the narrow boundaries of their actual knowledge, and shut in by the absence of truth. Surely if astronomy has gained, as a noble and elevating pursuit, by the discovery of truth, even in spite of authority, the appreciation of other sciences will not be less benefited by being taken out of the way of error, and by the wide distribution of sound knowledge, which at once feeds and chastens the imagination, and conducts it in the right direction. There cannot be a question that the most solemn and imposing ideas are those which are founded on knowledge and not on ignorance—on truth and not on falsehood.

No doubt it is the case that a mere study of detail may tame and injure the imagination in whatever department this study may direct itself. But in the information here given it has been the object to connect a knowledge of facts with the great general laws of nature to which they were related. The search after this higher order of truth is the real antidote to the danger incurred by the mere minute observer of facts. As we advance in knowledge, we thus rise, as it were, to greater elevations, and obtain not only a more distant view, owing to our better position, but a clearer and more transparent medium in which to observe these distant objects. Toiling step by step as we advance onwards—mechanical and fatiguing as our progress may be, and often must be—still in this search after lofty, general and distant truth, we strengthen the intellectual powers, augmenting not only the number of our ideas, but the means of generalising and rendering more truly available those already possessed.

There is, however, another, and hardly a less important or interesting view, that may be taken of this great subject. The minute study of Nature, combined with a knowledge of general laws, involves an actual contact with Nature herself, in her freedom, simplicity, and grandeur, and induces impressions derived from the idea of order and law, exercising a soothing and calming influence on the mind, and well fitting it for those noble exertions which we regard as inspiration, because we feel that they exhibit creative energy.

"It may indeed seem a rash attempt to endeavour to analyse into its elements the enchantment which the great scenes of Nature thus exert over our minds, for this effect depends especially on the combination and unity of the various emotions and ideas

excited; but if we would trace this power to its source, we must take a near and discriminating view of individual forms and variously acting forces. The aspect of external nature, when thus contemplated thoughtfully, is that of unity in diversity, and of connection, resemblance and order among all created things, however dissimilar in form."

It is this unity in diversity, however, which renders the minute study of Nature so essential to him who would produce such a representation of Nature as shall itself be suggestive, and be worthy of the name of art. And here again it is evident that truth in representation is a sacred duty and an inevitable necessity to the artist who delineates natural objects of whatever kind. To be true to himself—to be other than essentially false, he must be a student and an imitator of Nature. In the sublime idealizations of Raffaelle, it is well known that he has falsified the position of no one anatomical detail in the human countenance. In the drawings of Michael Angelo it is nowhere found that a muscle is added to or taken from the fair symmetry of the human frame. Does Raffaelle, in expressing celestial sweetness and softness, diminish the angularity of the male form, or, to give energy to a female face, represent an outline which is not truly characteristic of the sex? And ought the landscape-artist to venture to alter the colour—the form or the drapery which Nature has herself selected to appear in to human eyes. Can he with impunity modify and soften where she is rugged and stern—or will he, in order to give a false and paltry impression, produce an angle where she has left a curve? It is true that many have done all this, and have even passed undetected by the critic; they have succeeded for a time in attracting the eye and charming the senses. The clever artist may obtain credit for boldness, and may think it a great thing to have originated a peculiarity; but all this is done in the absolute certainty of being one day exposed and slighted, and one inevitable result will follow,—the verdict of posterity, and the general voice of reason, taste, and common sense will be given, and the pictures and artist will be alike neglected. Men soon learn that truth is better than falsehood; and permanent admiration never has been, and never will be, based upon a lie.

What then, it may be asked, is this truth that is so much vaunted? Is it a mere mechanical reprint of nature—is it a daguerreotype of some particular scene—does it differ from a copy, and does it demand no effort of the imagination? By no means is this the case. The imitation of nature that ought to be inculcated, is one of a kind that no mechanical effort can approach; for the genius of man—that spark of the divine nature—is needed for its perfect exercise.

It is necessary to study minutely all that is true and real, to imitate closely all that is lovely and grand, to know what harmony consists in, and how beauty and grandeur are produced. The senses only partially comprehend, and the uneducated intellect only half reflects on all that is influential in producing those impressions of the beautiful, which are really worthy of being transmitted to the canvas. A landscape, however truly picturesque, must be properly seen before it is appreciated. Nature is not seen only by the eye; she is not appreciated by the mere passing traveller, intent on matters of another kind—observation, taste, feeling, intellect and genius, all lend their colouring, and all help to render nature beautiful. The true artist is himself always true—true to art and true to nature—both external and internal; he is earnest, thoughtful, and reflective—for if he study nature he cannot be otherwise; he imitates, for he describes; but he throws a rich and warm glow over his description, and gives vitality and existence even to that which is itself inanimate and accidental—for the sparkling light of his genius shines over all, and whatever he touches burns with living fire.

Imitation, then, of this kind is not a mere mechanical art—and a picture, to deserve the name, must be something more than a permanent reflection. It must express thought, and feeling, and knowledge; and to be useful it must teach others also to feel and to know. It is no detraction from the merit due to a work of art to say that it excites proper feeling and teaches useful knowledge. On the other hand, there is no evil so great and so much to be lamented as that which is sanctified, as it were, by having the halo of genius spread around it; nor is there any ignorance so mischievous as that which induces the greatest and the most popular teachers to teach falsely and neglect truth as a thing of small import.

AGRICULTURAL GEOLOGY.

Nature and Origin of Soils.—Enough has been already said on this subject to give the reader an idea of the real state of the case, since all soils may be regarded as formed originally from the disintegration or decomposition of rocks. The former is a mechanical cause, connected with the atmosphere, and resulting from the alternations of dryness and moisture, and of heat and cold incessantly going on. The growth and decay of vegetation is another important agent, telling in the same direction, as no soil is available for useful plants, and those requiring cultivation, without something more than the ordinary constituents of rocks.

Climate, again, exercises a marked influence—first tending to break up all hard substances exposed to its action; while the torrents that fall from the clouds, and afterwards rush over the earth's surface, in tropical countries, are scarcely less influential in grinding down to powder and removing surface accumulations of any kind. In temperate countries like our own, the frequent alternations of the temperature within a few degrees above and below the point at which water possesses the smallest volume, (about 38° Fahr.), is another fruitful cause of destruction, by the alternate expansion and contraction of water in the crevices of surface deposits, and the consequent splitting up and breaking off the outer weathered coat of rock.

Decomposition is produced in rocks partly by oxidation or exposure, and partly by the infiltration of water containing acid or alkaline substances in solution. Both causes greatly assist the disintegration already alluded to; but rocks are very differently affected,—the weathering sometimes extending downwards twenty or thirty feet, or more, beneath the surface, and sometimes hardly visible. In all cases, however, where valuable soil is found, there is a considerable admixture of the surface rock with material conveyed from a distance, and with *humus* and *mould*, the brown permeable substances produced by the decay of woody fibre, which not only yield dried nourishment, but act indirectly, in a very important way, to render soils more generally useful than they would otherwise be.

Besides the soil, the subsoil exercises considerable influence on the vegetation of a district, and is often yet more nearly derived from the underlying rock. By mixing these two mineral substances together, the value of the former is often greatly increased; and by taking advantage of the condition and nature of the latter, the mechanical operation of draining is often greatly simplified.

It will be evident that, in a general way, a chemical investigation of any soil will be more valuable than any mere account of its geological position. While, however, in an unknown district, the age of a rock affords no valuable information for practical purposes, this is not the case where mineral substances of the same kind are usually met with in geological relation to each other. Thus, in England, the super-position of

rocks, and their general succession, being well known, the presence of a particular kind of sandstone renders it probable that rich marls are near, while another kind of sandstone,—little different, it may be, in some respects,—is yet indicative of magnesian salts; and another is likely to be associated only with tough clays and coal. These various associations, on which this subsoil mainly depends, seriously affect the value of land, and thus it becomes not only desirable but necessary that the farmer—to say nothing of the land-agent and valuer—should know something of what is likely to exist beneath the surface, and be able to judge of the subsoil and rock by the appearance and known geological position of what comes to the surface.

So again, whilst a knowledge of the mineral character of a rock, and its value for special purposes, requires that the chemist and the mineralogist should be referred to, there will arise questions of great practical importance, as to whether any quantity of such mineral as rock exists near at hand, and can be readily and cheaply obtained. In the case of limestone, these matters are of vital importance, and they involve considerations strictly geological. In an oolitic district, one piece of stone might lead to the knowledge of a bed being near; whereas in gravel the presence of the mineral would be merely accidental. In a district in which the rocks are not generally highly inclined, or much broken and fractured, it might be at once determined that a bed of limestone found was probably workable; whereas, under other circumstances, perfectly understood and not uncommon, it might, on the contrary, be highly improbable that such a bed, though found, could be worked to permanent advantage. Instances of this kind might be multiplied indefinitely, but it is unnecessary to do so. The ordinary and well-known conditions and varieties of stratified and unstratified rocks are sufficiently understood, and in the preceding pages have been sufficiently developed to enable the reader to comprehend the general principles,—the application of which to practice is so valuable to the farmer and land-agent.

In addition to the mixing of soils, and the advantage, under certain circumstances, of deep ploughing for this purpose, there are many points, in the practical treatment of land, which admit of the application of geological knowledge. Thus, where drainage is required, it can hardly be planned with propriety without some reference to the underlying material, and the position in which it exists. The drainage of fen lands, and lands near the sea, with little fall, but enough to produce a current of water when there is no obstacle, include one group of cases that require consideration. The drainage of uplands, where there is some fall, but where local peculiarities connected with the form of the land allow water to be retained, forms another group; and the drainage of land, where there is sufficient fall (and where there appear no reasons at surface for any accumulation of water, but where, notwithstanding, the ground does get choked, and prevents the advance of vegetables), also needs consideration, as involving a third class of phenomena.

Alluvial Soil.—Connected with this part of the subject may be mentioned the case of soils deposited at the mouths of rivers, and forming strips of the richest land, gradually widening towards the sea. The mud thus brought down by running water, and left behind where the current of the stream is checked, is called *alluvial*, to distinguish it from the accumulations of mud, sand, and pebbles—the result of accidental and occasional torrents, called *diluvium*. In some parts of the world, especially in the great plains extending between the Caspian Sea and the sea of Aral, vast tracts of flat country are occupied by great thicknesses of the richest soil; and elsewhere, as in parts of India, other circumstances have conspired to produce similarly valuable soils, whether for the cultivation of corn or cotton.

Causes of Fertility.—Soils being at once the habitation, the mechanical support, and the source of nourishment of plants, evidently require special treatment, and peculiar consideration. In addition to the vegetable matters which help to render them available, they require certain proportions of silica, alumina, lime, magnesia, and iron, besides potash and soda, sulphur and phosphorus, and water.

Fertility depends on depth, and on the texture and condition of the minerals that are present, as well as on the nature of those minerals. The actual proportion varies exceedingly, as will be seen on examining the proportions that have been found in the case of some of the most remarkable known instances. Those selected are (1) the mud of the Nile, celebrated in history as the most fertilizing of all materials, and constantly spread over the land in each succeeding year; (2), the *Tchornozem*, or black earth of the Aralo-Caspian Plains, which feed twenty millions of people, and export besides fifty millions of bushels of corn annually, bearing crops for years together; (3), the *Regur*, or cotton soil of India, where constant successions of crops—one of cotton, and two of corn—have been produced for the last twenty centuries; and (4), the rich and valuable soils of various grazing counties of England, as Devonshire and Cheshire, derived from the red marl. Of these the tchornozem is twenty feet thick, and contains, in addition to its solid ingredients, $2\frac{3}{4}$ per cent. of nitrogen, while the regur varies from three to twenty feet, and is chiefly remarkable for its large per centage of carbonate of magnesia. The Nile mud contains much the largest proportion of organic matter.

	Nile Mud.	Tchornozem.	Regur.	English Soil. Red Marl.
Silica	42·50	75·00	48·20	70·20
Alumina	24·25	9·09	20·30	19·20
Magnesia	1·05	—	—	—
Carbonate of lime	3·85	small.	16·00	0·40
Carbonate of magnesia	1·20	?	10·20	—
Oxide of iron	13·65	5·56	1·00	6·00
Water and organic matter	13·50	6·95	4·30	4·10
Chloride of sodium	—	—	—	0·10
	100·00	96·60	100·00	100·00

Various Kinds of Soils.—It will easily be seen that as far as soils are derived from underlying rocks, they may be divided into four groups.

1. Aluminous, or clay soils.
2. Calcareous, or lime soils.
3. Siliceous, or sandy soils.
4. Soils derived from basalts and granite, and of mixed character.

Of these the simple and ordinary combinations require, indeed, to be known, but they occur in rocks of all geological periods. Thus clay soils consist of silicates of alumina, mixed up with more or less sand, and frequently with lime, and are usually coloured with iron. When combined with from thirty to forty per cent. of sand, they become clay-loams. When there is from forty to seventy per cent. of sand, they pass into true loams and loamy soils; and not till the per centage of sand is nearly ninety do they become sandy soils. So again with from five to twenty per cent. of lime the soil becomes marly; and not till it has more than twenty per cent. of lime does it receive the name of a calcareous soil.

Of the various clays in England, those of the older tertiary, middle secondary, and

newer Palæozoic periods, contain but little calcareous matter; and those of the gault and lias but little sand, and much calcareous matter. Most of these soils are close and retentive. When well tended and highly cultivated, they produce large crops of corn and other grasses, but are not suitable for the turnip. When poor and undrained, they grow coarse grass and oats; but they require drainage and dressing with lime, sand, gravel, or burnt clay, to render them really available. They usually contain the silicates of alumina (clay) to excess. The fen districts of Lincolnshire, Huntingdonshire, Cambridgeshire, and the neighbourhood, are good illustrations of the high capabilities of many of these unpromising tracts; more especially for heavy corn crops.

Calcareous rocks, when perfectly pure, frequently yield barren soils, as may be seen both in the case of soft chalk and hard limestone in various parts of the British islands. These rocks are, however, rarely without a certain proportion of clay and silica; and, together with a little vegetable matter, they make excellent, though often light soils. Soft limestones (chalk) absorb much water, but do not give it out again freely by draining naturally into crevices; although by evaporation it is easily removed. Thus most of the limestone soils soon dry at the surface after rain, but rarely suffer severely from drought.

Sand-soils are of various kinds, but always require admixture with limestone or clay, or both. Pure sand has no coherence, and contains nothing to which plants can attach themselves, or from which they can derive nutriment. Combined with other earthy substances of almost any kind, sands are useful for certain purposes. Water enters sand freely, and runs through and into crevices without being retained in the mass; and in this way sand greatly differs from limestone and clay.

Alluvial soils derived from rivers generally consist of fine mud, and contain an admixture of mineral constituents, and a certain amount of organic matter, both animal and vegetable, mixed with them. Diluvial soils, on the other hand, are more usually stony, and often barren, consisting of large gravel, boulders, and fragments of stone mixed with clay.

Many of the igneous and metamorphic rocks decompose into soils of the richest and most valuable kinds. Thus lava and basalt, in themselves rough, hard, and apparently altogether unfitted for agricultural use, only require a little time, and a certain amount of weathering, to produce the finest soils in the world. Even decomposed granite is often very valuable; and some of the porphyries may be recognised as the underlying rocks in the case of rich soils. Usually, however, these hard rocks, when partially or entirely crystalline, resist atmospheric action too long to allow of much vegetable soil accumulating on them. Thus the granites, gneiss rocks, slates and schists, are presented in bare mountain masses,—occasionally, perhaps, covered with a few trees; but, except where the atmosphere is constantly moist, they are essentially naked, and exhibit grandeur rather than beauty or economic value.

Mineral Manures.—The admixture of soils, so as to produce a mineral manure, is a matter of the highest importance in the practice of agriculture. It requires a distinct appreciation both of geology and chemistry to do this effectually; and certainly no farmer should be ignorant of what probably exists a few feet, or a few dozen feet, below the surface which he cultivates. It is now some time since the various soluble phosphates were found to produce a great effect, especially on root crops, such as turnips; and the discovery of mineral phosphates, which, by chemical treatment, were made valuable for manure, was an era in the application of science. To the scientific knowledge and experience brought to bear through the agency of Mr. Lawes, of

Rothamstead, near St. Albans, beds of pebbles, forming a large part of the gravel cliffs of Suffolk and Essex, have been found worth working and removing to the neighbourhood of London, where they are treated with sulphuric acid, ground up, and mingled with other substances, to form a valuable mineral ingredient for certain soils. These pebbles consist chiefly of phosphate of lime; and other deposits and veins of the same substance are no doubt to be found in England and elsewhere. Their value is considerable, and they are well worth careful search. These are mentioned as affording good examples of the application of mineral manures to agriculture, even when the minerals found require preparation of a somewhat elaborate kind. The admixtures of chalk with stiff clays and other soils of the same kind, are less complicated, but hardly less important, inasmuch as they are everywhere possible, and require less knowledge and fewer experiments. To apply in this way with advantage the knowledge derived from the study of geology, the farmer must know familiarly the structure of the earth in his neighbourhood. He should be aware, not merely of that which he can see directly before him and beneath his feet, but what rocks are below the surface—how they are placed—what they contain—and how they can be best reached or avoided. This knowledge of structure, and the application of it, is "practical geology" of the best kind.

Conclusion.—In this brief outline of operations concerning the science of agriculture, as based on actual observation of the earth's structure, and distinguished from mere empiricism, an endeavour has been made to illustrate a great subject, little understood, and less practised; but upon the due application of which much of the prosperity and happiness of a large proportion of the population of England for the future must really depend.

If farmers and agriculturists, availing themselves of the knowledge and experience of others, as well as that acquired by themselves, are willing and anxious to improve and fully cultivate their land, they may unquestionably now obtain a fair profit for capital fairly invested; but if they neglect the simplest laws of nature, and the observation and comparison of the operations daily presented to their notice, they will be the principal sufferers, although the general interests of the country will no doubt also be effected.

Nature has provided everywhere indications of the internal structure of the earth; and these are in no case so clear, and in none more important and valuable than where they refer to the culture of food plants. The kind of mineral riches required for this purpose is generally present near the surface, is easily understood, and soon brought into use. It is therefore quite certain that every one concerned in the management of land should be acquainted with the nature and range of each geological formation; the conditions and circumstances under which these come to the surface in his own immediate district; the texture and derivation of the soil and its relation to the sub-soil; the dip and strike of the strata, and the form and surface of the land. Where an estate is situated on several beds, each must be examined; and the natural as well as actual condition of the soil must be determined, and mixtures of soil suggested. The extent and influence of faults and disturbances of the regular stratification must also be fairly considered; and the whole plan of cultivation must have some reference to those points which have been here referred to.

When draining operations on a large scale are to be commenced, and the engineer steps in to assist, or precede the farmer, he also must understand what is beneath the surface before he can fitly apply his skill and develop the resources his science suggests. No work is really satisfactory and sufficient either in agriculture, or in that

department of engineering useful to the cultivator, which does not refer to geological structure, and which does not fairly estimate the facts now clearly determined concerning the earth's ancient and recent history.

ENGINEERING GEOLOGY.—DRAINAGE.

Not only in questions of drainage on a large scale, but wherever it is required to reclaim lands or construct public works; whether it be the question to lay out extensive operations of well-sinking, or contrive the best mode of impounding water for the use of towns; whether the selection of lines of railroad, or other roads where deep cuttings, tunnels, and heavy embankments be the object in view; or whether it be the construction of docks and harbours, the selection of sites for new towns in the colonies, or any of the numerous other engineering operations, where the structure of the earth influences the operations and works to be performed,—in all such instances a sound knowledge of Geology is necessary. In cases where large masses of stone-work are to be put upon the ground, and massive public buildings erected, distinct information of a similar kind is needed by the architect, who has occasionally also to decide on engineering questions, and on the selection of material. The application of geological information to engineering is thus capable of being grouped under various heads, which may be thus enumerated—(1), drainage; (2), water supply; (3), material for construction and decoration. We proceed, then, to—

Drainage of Land.—The artificial drainage, and ultimate reclaiming of large tracts of rich land hitherto subject to destructive inundation, or permanently under water, is one of the most important matters on which engineering skill can be exercised. Attempts of this kind have frequently succeeded, and the advantage in such case is enormously great. They have sometimes failed, and the loss is correspondingly ruinous.

It is chiefly in countries where land is very valuable, or where the position of the land supposed to be reclaimable is of great political advantage, that such operations can be properly attempted. A large part of Holland, and the extensive fen lands of Lincolnshire, Cambridgeshire, and adjacent counties in the east of England, afford admirable illustrations of the two most remarkable conditions of successful drainage of this kind. The drainage of bogs, in the interior of a country, is a somewhat different process; and the drainage of uplands generally, for ordinary agricultural purposes, on a small scale, requires only the application of a small amount of geology and a little surveying knowledge of the commonest kind.

The fen lands of Holland are derived from the delta or mud accumulations at the mouth of the Rhine, and are therefore not at all above the level of high water in the adjacent ocean. The fens of Lincolnshire, on the other hand, though often subject to inundation, are really above high-water mark. In the former case, therefore, the water has to be lifted off the surface into dykes constructed for that purpose, after artificial barriers have been constructed to prevent the incursion of the sea, and the drainage can only pass into the ocean at low tide; but in the latter the fall is sufficient to allow the water to run off continuously after such barriers have been placed. The construction of the barriers and dykes, and the mode of lifting the water, and conducting it to an outfall, are all objects of engineering enterprise in Holland and in England; but with us the chief object in view is that of providing a clear and direct path for the surplus water to escape. The Dutch draining engineer has not to trouble himself with the structure of the underlying rock, since the only material

with which he can have to deal is the river mud, generally of great thickness, and of uniform character. The English engineer has to consider how and where he can safely cut or construct his artificial channels, to discharge the rivers, and empty lakes, in a district where the rocks to be dealt with are both varied in their character, and different in mechanical position.

The existence of the fens of Lincolnshire is due to the fact that two large deposits of tough impermeable clay, of the oolitic period, there overlap without any intermediate draining stratum. These beds have a regular, though very small fall towards the sea; and without some check to the entrance of the water, they would be subject to injury from occasional high tides. They are traversed by numerous streams, bringing down water from the higher ground in the interior; and parts of their surface where depressions exist are covered with large ponds or lakes of fresh water. The dip of all the beds being seaward, no natural barrier exists either on or near the coast tending to keep back the water flowing towards the sea, or check the advance of the sea during tides of unusual height.

It is not difficult to explain the process by which a low flat coast, like that which our fen lands originally presented to the sea, has in time become so much covered with water as to be quite valueless without artificial drainage, although there originally existed a natural fall sufficient to carry off the water. If we assume the condition of the land, at some distant period, to have been dry and covered with forest, being then naturally drained by streams running directly, and without interruption, to the ocean, it is easy to see that an accident, which should divert the course of a stream from its original line, or any obstacle that kept back part of the water in a pond or lake, must, by checking the rate of progress of the water, produce an accumulation of mud, either in the river or at the sea coast. Even under the most favourable circumstances, a bar or bank of mud must always be formed when a river after running over a clay soil, with a moderate current, comes directly in contact with the tidal wave. This check to the course of the water obliges it to deposit a part of its load of mud, both because the sea-water is heavier, and because its momentum is greater. The fresh water partly floats over the salt, but its motion being interrupted, the mud soon begins to be deposited. In any way it must appear that the first check given to the direct course of the stream—the first bend or sinuosity produced,—inevitably tends to make a second curve, and so on, until the stream, originally straight, becomes serpentine. But if a stream has to go a certain distance to the sea through flat lands, its rate of motion is manifestly affected by this; and if the original rate has been slow, the volume of water not considerable, and the distance the water has to travel should in time become doubled by the more sinuous course it is made to follow, the rate of motion must be nearly halved, and the power the stream has to convey mud and silt is then proportionally diminished. Thus everything tends to increase the evil; and it can only be corrected by cutting a fresh and direct outlet for the water, and entirely checking that tendency to wind in sinuous curves so common in all streams meandering over flat clay. This done, the outlet kept clear, and the embankment towards the sea in good condition, a fen district above high-water mark becomes effectually and permanently drained.

The process of *warping*, or admitting muddy water, or water loaded with silt, to enter low flats at flood or high tides, there to remain until it has deposited its mud, and afterwards allowing it to run off clear when the tides are low, is an important means of raising the general level of large, low tracts near the sea, until they approach the highest level of high water, and become permanently reclaimed. This is often con-

nected with large draining operations. The removal of water, where it is accumulated on mountain tracts under vegetation, as is the case in many parts of Ireland and elsewhere, may often be effected by very simple means, when the nature of the underlying rock is known. This process is analogous to that of draining for ordinary agricultural purposes.

THE GEOLOGY OF WATER SUPPLY.

Distribution and Circulation of Water.—In an earlier part of this treatise, while speaking of the distribution of water on the earth's surface, by means of the atmosphere, some account will be found of the way in which a circulation of water is kept up, and the supply of springs and rivers rendered permanent. A very brief recapitulation of these facts may here be useful.

The earth we have seen consists (see page 5) of three forms of matter—aërial, *fluid*, and *solid*; the agency of heat keeping all the different substances in that one of these conditions which belongs to it at the particular temperature to which it may at any time happen to be exposed, but in a general way leaving water fluid, the atmosphere gaseous, and the remainder solid. Air, however, as well as earth and water, is capable of retaining in a state of suspension or solution some quantity of most of the fluid, and even solid substances with which we are acquainted, and generally contains on an average, in its usual state, nearly four grains of water in each cubic foot, which is equivalent to about one pint in a room fifteen feet square and eight feet high. Thus it results, by a simple calculation, that the column of atmosphere over each acre of the earth's surface contains about a quarter of a million of gallons of water in what may be regarded as its normal condition, and without feeling damp, or tending to be deposited in mist or rain.

But the quantity present in parts of the column, especially those nearest the earth, is capable of being very greatly increased under favourable circumstances. Thus in summer, at a temperature of 70°, more than eight grains in the cubic foot, or double this amount, can be held, while in winter the quantity is much less than four; so that, if we assume a limited thickness of the atmosphere, we shall find that each yard of height of the column already alluded to, whose base is one acre, may, under this altered state of affairs, contain no less than sixteen gallons of water; and that, by change of temperature and other causes, this power of retention is capable of rapid reduction to the normal quantity of four gallons. The large amount of twelve gallons of water may thus be actually discharged from such a space of air in a short time; and this calculation gives an approximate measure of the water-contents of that part of the air occupied by clouds, which are well known to be accumulations of vapour originally dissolved in transparent air, but made visible by changes in the atmospheric condition. An acre of cloud, five hundred yards thick, may discharge any quantity up to six thousand gallons of water, provided the condition of the air, in regard to temperature, vary from 70° to 40°. The actual quantity that falls will depend partly on the rapidity and extent of change, and partly on electrical conditions.

Thus if a rain-cloud, five hundred yards thick, move over the land on a hot summer's day at the rate of three miles an hour, and deposit one twenty-fifth part of its available water, there will occur a shower of rain, and the amount of rain falling will be marked by the rain-gauge as one inch. This corresponds to about twenty thousand gallons of water on each acre of ground over which the shower has fallen at the assumed rate. Such a shower would be unusually heavy; but even a larger fall often occurs in summer.

The total rain-fall in one year, in the neighbourhood of London, is only about twenty-five times this amount.

The reader will understand that such a statement is to be taken only as approximative; but it is sufficiently accurate to serve as an illustration.*

The mean rain-fall in all England, taken one year with another, is considered to be on the whole about thirty inches; but the average on the plains is twenty-four and a-half, and on the mountains forty and a-half inches. The average fall during the spring and summer months on the plains is ten and a-half, on the mountains eighteen and a-half inches; and during the winter and autumn months, on the plains, fourteen—on the mountains, twenty-two inches.

The total amount that sometimes falls in one year is often far above or below the average in particular spots. Thus, at Seathwaite, in the Westmoreland lake district, nearly one hundred and sixty-one inches are recorded—this being equal to the largest average in the tropics.

The actual amount of water that falls over the whole earth in the course of one year is calculated to be equivalent to one yard in depth, if retained on the surface of the land.

Of this large quantity of water that may be regarded as "in circulation," it is supposed that about one-sixth part runs off in rivers, and that one part sinks into the soil; while the rest is immediately re-evaporated before it has produced any effect. The supply for various economic purposes may be obtained either from rivers directly; from natural springs rising at the surface; from water impounded from springs obtained by artificial sinkings and borings, but in which the water rises to and flows over the surface; or from deep wells into which water flows, but from which it must be pumped.

It has been usual to obtain water for the use of towns either from rivers or springs—the water being sometimes conveyed from a considerable distance by aqueducts or pipes. More recently it has been thought advisable to collect and store water in large reservoirs, whence it is conveyed to the required spot. Some of the largest manufacturing towns in England have of late years resorted to this as the best plan. Manchester, with a population of 400,000, is supplied, from a distance of sixteen miles, by a reservoir about eighteen thousand acres in extent; Newcastle-on-Tyne (population 120,000) by about four thousand acres, twelve miles off; Bolton (60,000) by five hundred acres, four miles distant; and arrangements are being made to supply the 400,000 inhabitants of Liverpool by reservoirs occupying ten thousand four hundred acres, at a distance of twenty-six miles from the town. In all these cases the water is pure, and can be supplied with great advantage in sufficient quantities. The rain is collected over a certain area by intercepting all the streams that would otherwise convey it away to a lower level; but to do this effectually, it is absolutely necessary that the rock beneath the reservoir should retain the water, and not contain any injurious minerals. To determine this, not merely a surface survey is necessary, but a geological survey to learn the nature of the beds, their dip, and the outlet, if any, of such as are permeable, and also (most of all) the presence or absence of faults which

* It should be remarked that, to render this illustration less complicated, it is assumed that the whole column would be of equal density. This is not the case in nature, in consequence of the elasticity of air; and the portion of the column equivalent to a yard in thickness near the earth's surface would be many times that thickness if taken at a considerable elevation. Still, the general argument and the conclusions remain the same.

might immediately, or ultimately, drain off the water intended to be stored. On the other hand, advantage can sometimes be taken of natural springs to act as feeders to the supply.

The cases where very large quantities of water issue from the ground at one spot, and are to be depended on as a permanent source of supply, may be supposed to be rare. There are, however, very remarkable instances recorded. Thus, at Vaucluse, there is a spring of water yielding from thirteen to forty thousand cubic feet (eighty thousand to a quarter of a million gallons) per minute, varying according to the season. This quantity is sufficiently large to supply a population double that of London. Another fountain, also in the south of France (near the town of Nismes), yields as a minimum one hundred and fifty gallons per minute, the quantity occasionally increasing to one thousand gallons.

But water is far more frequently obtained from springs reached by boring into the earth to some depth, either to a natural reservoir formed in a crevice or cavity in the strata, or else to some particular rock that allows water to permeate freely through it, and is fed from the surface, or from a distant source. It is well known, and easily proved, that all rocks contain water; but that, while some suck up a quantity which may be very considerable, and retain it like a sponge by capillary attraction, others merely receive it mechanically, and soon part with the greater proportion. As the best examples of these two extreme conditions, may be mentioned chalk and sand respectively. A cubic yard of thoroughly wet chalk contains, in addition to the quantity of dry chalk that occupies that space, one third of its bulk, or nine cubic feet of water, equivalent to upwards of fifty gallons. No part of this large quantity would leave the chalk by simple drainage; so that a well sunk in chalk, however wet the rock may be, would contain no water if the chalk were perfectly compact. This, indeed, is never the case; and there are always a vast number of small crevices, and occasionally some very large ones, through which the water flows with freedom enough, and soon clears for itself a passage. Thus a well in chalk often yields water, though the chalk does not become less soaked in consequence.

Sand, on the other hand, contains water also in large quantity, but under very different conditions. Pure sea sand will contain, in a cubic yard, about the same quantity of water as the same volume of chalk, but would part with almost all of its contents into a well sunk into it, and regularly pumped from. This is easily observed, and may be proved by experiment. The various kinds of sandstone, more or less pure, will necessarily contain and part with water in very different proportions. Sandstones moderately loose in texture, such as the new red sandstone in its ordinary state, hold from four to five pints of water in the cubic foot, and will part with a large proportion of it. Rocks of this kind are, however, much cracked, and often have hard impermeable bands cutting off the communication between the different parts of the same rock. The crevices in the sandstone are not always, indeed, impermeable; and thus it happens that in some places water is freely conducted, and in others almost checked in its progress through this rock; and it is difficult to determine beforehand what the particular result in a given locality will be. Under the most favourable circumstances, however, it may be considered that sandstone will yield to hard pumping a million of gallons daily from a deep well.

It is, however, well known by observation, and is a matter of no little importance to engineers, that, whether in sand or chalk, a well sunk and kept constantly drained (technically called a well of exhaustion) must necessarily drain the surrounding rock

to some distance, if only from the amount of friction that inevitably takes place when water flows from one part of a rock to another. Thus there is formed, aroundsuch a well of exhaustion, a conical space; the vertex of the cone being the bottom of the well, and the base at the surface embracing an area proportioned to the nature of the rock and the depth of the sinking.

Artesian Wells.—The cause of success in what are called "Artesian wells" is easily explained by a reference to the position of strata. Thus, in the neighbourhood of London, the chalk is present on each side of the valley of the Thames, and is known to pass under the clays and sands which form the actual strata at the surface, and extend to a considerable depth. These clays and sands are thus in a kind of chalk trough, and there are generally sands between the clay and the chalk. The clays, it is hardly necessary to say, are absolutely retentive, neither allowing water to be obtained from them nor to pass through them. They act as a barrier; and if water comes in beneath them, conveyed through the sands, it remains there under pressure, and unable to get out. In such case, if a well is sunk, or a boring made through the clay to the sands, or if necessary into the chalk, water will not only be reached, but will, in finding its level, rise in the well sometimes to the surface, and sometimes even above it, though often only a part of the way.

Should it happen, as is not uncommonly the case, that no such trough exists, but that some of the beds are permeable and others impermeable, but all parallel to each other and going down to considerable depths, the former may become soaked or filled with water up to or very near the surface; and then, also, if these are pierced at a distant point by a well sunk through the clays or stone, the water will rise, obeying the same law. If there be faults in any part, it may happen that these being open may carry the water away; but they may also be closed below, and allow the water either to accumulate or to be delivered in a natural spring. So, also, it is not uncommon to see springs of water issue from a hill side, where permeable beds are suddenly cut off.

Intermittent Springs.—In some parts of the country there has been observed a peculiar condition of the springs, which requires some explanation. The water of these springs flows, perhaps, regularly and steadily for a certain time, without any apparent reference to the state of the weather. At length the flow ceases; the season, perhaps, is unusually wet, but still no more water is seen, and the source is nearly or altogether dried up. After an interval—it may be of some months, or even years—the water begins once more to flow in a powerful stream; and this time, also, it may appear to be without reference to the season or the rain falls of the preceding or present year. These phenomena are repeated at intervals, more or less irregular; and such streams are properly called *intermittent*. Nothing can really be more simple than the cause of this. A large cavity in the interior (generally in limestone rock) serves as a reservoir, and is communicated with from above by crevices, through which the surface water drains. Another crevice or passage exists, taking its rise near or at the bottom of the reservoir, and leading to the place at which the spring flows, which may be at a distance of many miles from the chief sources of supply. This passage, however, is irregular, and instead of running directly, rises, in some parts of its course, nearly to the level of the top of the reservoir. Until the reservoir, then, is full, no stream will run out; but when the water rises so high as to be above the highest point of the passage it runs over; and, provided the delivery point is below the bottom of the reservoir, all the water will then be drained from it, because the passage in

question acts as a siphon—a contrivance often made use of, and which will be described and fully explained in the volume on "Natural Philosophy."

Water Supply for Towns.—It is desirable here to say a few words on this subject, as involving some important considerations in which geological investigations are extremely useful. It is clear that the sources of supply must depend much on local circumstances. Where the population of a town is not extremely large, and the rocks yield water freely from wells of moderate depth, this source is extremely valuable, and may be sufficient. Where, however, the population is great and rapidly increasing, and where water is needed for manufactures, steam-engines, and shipping, as well as for drinking and household purposes, there will arise a necessity for some more certain and ready means. Rivers, if sufficiently large and rapid to secure both quantity and quality, and storage in reservoirs at a distance if the river supply is for any reason unavailable, form the natural means that suggest themselves.

Absolutely pure water is not to be obtained in nature; and fortunately it is not essential—perhaps not desirable—for the ordinary uses of animal and vegetable life. In ordinary cases, rain-water contains ammonia, and in or near towns is always tainted with various impurities, introduced into the atmosphere where large numbers of human beings and animals are collected together, and especially where household fires, and manufactories of various kinds involve the combustion of very large quantities of mineral fuel. Spring water contains numerous mineral substances, chiefly salts and gases, obtained from the rocks passed through; and as water is an almost universal solvent, the variety of these is very great. In ordinary cases, the salts of lime and soda are chiefly abundant; but salts of potash and magnesia are also common. The salts include chlorides, carbonates, sulphates, and phosphates. Iron, silica, and very small quantities of organic matter are occasionally found.

River water contains, in addition to the various substances obtained from springs, and from the rocks over which the stream passes, a quantity of organic matter, both of animal and vegetable origin, which in the neighbourhood of large towns usually includes much sewage matter.

It might be supposed, and has often been stated, that where this deposit is constantly stirred up by the periodical passage of the tidal wave, the water cannot be in any other than an unwholesome state, and unfit for general use. There are, however, causes at work tending to purify the water by simple exposure. The decomposing animal and vegetable matter is rapidly removed from a mischievous condition, partly by aëration, and partly by those myriads of animalcules which are often spoken of as among the impurities, but which really collect the offensive particles and re-introduce them into the realms of life. River water is freed from its impurities, even of the worst kind, in a wonderfully brief space of time, and, with the aid of a little filtration, is admirably adapted to household use.

The purest water is that which is found in mountainous or hilly districts, where there is abundant rain-fall and a surface of hard rock; but it is remarkable, that among wells those sunk deepest generally contain less solid matter than those moderately shallow. The quantity varies from ten to about seventy-five grains in each imperial gallon in deep wells; but reaches to one hundred or even one hundred and twenty grains in some near the surface.

General Considerations.—It must be unnecessary to add much as to the great general interest and practical importance of this subject of water supply.

Its bearing on the general health of the vast metropolis of the British empire is

now more than ever recognised; and the necessity of providing, in some way, for the increasing wants of the population, is daily more and more felt. Methods have been suggested of almost all kinds by which the existing want might be supplied; but it is a subject of regret to find that, for the most part, these are incomplete, either owing to intentional neglect of existing valuable and important resources, or from a false estimate of other resources. It is, no doubt, easier and more effective, in discussing such subjects, to take up one side and press the advantages of some one method; but this way of considering a great public question ought not to be adopted by those who aim at the general benefit of mankind. It has been the object here to introduce the subject of water supply as connected with the use and progress of geology. Viewed in this light it may be remarked that the essential desideratum in London is a uniform and constant supply of water, tolerably pure, amply sufficient in quantity, supplied to every house, and sold at a small cost to each housekeeper. We do not want, nor perhaps could we accomplish, any complete reversal of the present modes of obtaining water; for these have really been so far successful as to give us, even at present, a larger and better supply than is possessed by any other city in the world. While, therefore, we desire to improve our condition, we should be very unjustifiable to turn round and repudiate those who have brought us thus far; and it would be much wiser and safer to show the existing proprietors of water-companies that their true interest lies in enlarging their present resources, and increasing the circulation of that fluid which is as essential to the health of a great city as the blood is to that of any individual.

In concluding this subject it is not out of place to direct attention to the interesting and beautiful illustration it affords of the mode in which the various conditions of our earth assist each other, and help to render the whole so perfect, and so well adapted as we find it for the support of animal and vegetable life. By a succession of contrivances, not difficult to follow, we see that a portion of the water, which at one time forms part of the great ocean, where it holds certain salts in solution, is distilled and absorbed into the atmosphere, in a pure state, by the passage of a current of dry air over it. The pure water thus dissolved in the atmosphere is carried along with the air to great distances, reaching at length the land, and there, owing to some changes, it appears in a visible form, and is still conveyed onwards in the form of *cloud*. In this manner the watery vapour floats over extensive districts, or remains suspended in mid air, until at length it can no longer be supported, when the particles of vapour collect into drops, and sink to the earth as *rain*.

Of the rain thus fallen a large proportion is deposited on some sloping ground, or on mountain sides, to which clouds are readily attracted, and thence descends in brooks and rivulets to join larger streams; these soon become rivers, and thus a portion of the water again passes directly back into the ocean. Another part descends into the soil, and becomes at once combined in vegetable or animal organization, not re-appearing to us in the form of water. But there is a third portion, which has other duties to perform. A considerable quantity of the rain that falls sinks gradually into the earth, and, owing to the peculiar arrangement of the rocks, and stones, and clays, it is received into the permeable strata and internal reservoirs of the earth, as into a well-contrived magazine, and is there retained for a time, until at length it is given out either gradually in gentle streams which help to fertilise the earth, or poured forth to supply the wants of man, who, by the exercise of his ingenuity, is able to derive profit from the admirable resources of nature, by imitating her methods, and adapting them to his purposes.

The internal structure of the earth is thus made available in supplying a substance absolutely necessary to organic existence, and hardly otherwise obtainable. It requires very little consideration to perceive how essential is the actual arrangement of the mineral ingredients of the earth to the fertility of continents, since by its means only a part of the rain that falls so abundantly on the flanks of mountain chains sinks down beneath the surface and re-appears in the plains.

ARCHITECTURAL GEOLOGY.

Nature of Materials.—These include a large number of natural substances, which, from their hardness and tenacity, can be used for purposes of construction without any further preparation than cutting them into convenient forms.

Of stones, properly so called, capable of being adopted for construction, there are two classes, one including all those commonly used in squared blocks and in the solid, often existing in large quantity, and obtainable at moderate cost, but having no very special tendency to split or work in any particular direction; and the other, such minerals as are chiefly employed for roofing and paving, which split readily into very thin portions, as slates, or are capable of being worked into thicker slabs and flag-stones, having parallel faces.

The building stones that are best adapted for general use in any particular district are naturally those that combine the greatest amount of durability with moderate cost; and as the cost of transport to any distance must be a serious item in the expense, the nearest will be, *cæteris paribus*, the best. But the durability, and therefore the ultimate economy on a large scale, is by no means easy to determine without careful and minute investigation or long experience; and thus a number of inquiries are necessary in reference to those materials which, being the nearest at hand, would first be suggested for use. Questions concerning building material include a large number of geological considerations both as to the nature of the stone, the mode in which it lies in the bed, the probable result of the exposure to which it will be subject, and the probability or otherwise of sufficiently large quantites being obtainable to justify the opening of a quarry.

Valuable qualities of Building Stones.—The ordinary building stones are either freestone or granites; the former being usually bedded, and their value depending a good deal on the conditions in which they are presented for use. The latter are not usually bedded, but are naturally broken into tolerably regular forms by joints. Joints also exist in stratified rocks, and greatly assist the quarryman. The points to which attention should chiefly be directed are:—(1.) with regard to position and quantity—that the stone be well and conveniently placed; abundant; and accessible both for quarrying and removal. (2.) As to the nature of the material:—that it be neither too hard nor unnecessarily heavy; workable at moderate cost; able to bear a heavy superincumbent weight without crushing; and sufficiently durable under the exposure to which it is liable. These are matters independent of geological age, but on which many results of geological inquiry throw great light.

The methods of investigation, usually adopted with regard to stones submitted for inquiry, are not very numerous or complicated, and may be here briefly referred to. It must be remembered that the climatal and atmospheric changes to which stones are to be exposed, introduce by far the most numerous and important causes of disintegration and decomposition; and also that, without some actual experience on the spot, the exact effect of atmospheric action can hardly be discovered. The material, composition,

and texture of a stone, will, however, greatly influence the nature and extent of all destructive changes to which it can be exposed. When, then, a stone is submitted for trial, the first things to be determined are its *mineral character* and *chemical composition*, so far at least as to determine what are its chief ingredients, and whether it contains any that are unusually subject to decomposition. As an example of the importance of this, it may be enough to mention, that sandstones, limestones, and granites behave in a manner totally different under exactly similar exposure; and that the presence even of an extremely small per centage of some of the alkalies in the two latter is injurious in the highest degree, although other alkaline bases seem to have little effect. Having determined the nature of the stone, its *hardness* (both in the quarry and after exposure), and its *brittleness*, two very different things, should next be made out in relation to some admitted standard. The best standard will generally be the cost of working. The *weight* is a quality also important, and more easily determinable, and is usually estimated by stating the average weight per cube foot; but it may also be taken more accurately from the specific gravity. As, however, it is difficult to get a precisely average sample of small size, the former is the more practical as well as the easier method.*

The *cohesive power* must next be settled; for on this point much of the use of the stone for large buildings depends. It is best ascertained by submitting small cubes of the average quality of material to slow pressure under a Bramah's press, until the stone first cracks and afterwards crushes. The number of pounds' pressure on the square inch of surface that produces this effect will give some measure of the cohesive power; but in practice it will never be possible to get all the stones equal to the average, and therefore very great allowance must be made for weak, bad, and cracked blocks. Still the information to be obtained by experiment is of value, and may be trusted in comparing different qualities of material for special purposes. It must be borne in mind, in this as in other matters, that the strength of a construction or material is the strength of its weakest part.

Brard's Method.—The *absorbent power* of a stone, or the quantity of water absorbed on exposure of the surface to water, may be determined either with or without the use of the air-pump. On this absorption in some stones, almost the whole weathering depends, while in the case of others it is but an indifferent guide. In order to determine the real extent of damage resulting from absorption, an ingenious method was contrived by a French engineer (Monsieur Brard), which has since been frequently employed in this country. The method is based on the idea that the expansion produced during the efflorescent crystallization of certain soluble salts on the evaporation of water from a saturated solution of such salts absorbed by the stone, will resemble in its effects the expansion of the rain water absorbed when the material is subjected to those changes of temperature near the freezing point, to which much of the destruction of building material in our climate is generally owing. To determine the durability of a stone, therefore, a block is taken of convenient size (two-inch cubes are the most convenient), and boiled for half an hour in a saturated solution of Glauber's salts (sulphate of soda), consisting of about a pound of salt to a quart of water. When taken out, the block is suspended by a thread over the vessel in which it was boiled, and within twenty-fours will be found covered with crystals. As soon as this is the case, it is dipped in the same water in which it was boiled, and the dipping must be

* It is sometimes thought advisable to compare the specific gravity of the unbroken stone with that of the crushed fragments. The difference is sometimes considerable, and marks the compact or loose state of aggregation of the material.

repeated at intervals as often as the crystals appear during a period of four days. By each dipping the portions of stone forced out by the crystallization will be left in the liquid; and at the conclusion of the experiment, all the fragments of stone at the bottom of the water are collected and carefully weighed. It is considered that in the time mentioned (four days), the stone will have been so much disintegrated at and near the surface, by the forcing out and washing away of particles in consequence of the successive crystallizations of the salt, as to enable us to form an idea as to its relative durability. In the case of some limestones, the quantity of stone lost may amount to as much as twenty grains, the original two-inch cube in its dry state having weighed from ten to twelve ounces. In other limestones the loss has not amounted to more than a tenth of a grain. The latter would be estimated to be ten times as durable as the former. In sandstones there is occasionally no result; and probably no very great dependence can be placed on the method, except in calcareous rocks, or at least in those which owe their compactness to a calcareous cement.

The materials met with and commonly used in this country may be thus grouped:—(1) *sandstones* of various degrees of fineness; (2) *limestones* consisting of carbonate of lime more or less pure, or mixed carbonates of lime and magnesia, the latter being designated *magnesian limestones;* and (3) granites and other crystalline rocks, including porphyries and basalts.

Sandstones.—The sandstones or grits usually consist of grains of sand, or small pebbles, cemented together either by silica, the salts of lime and magnesia, oxide of iron, clay, or an admixture of two or more of these. When the pebbles are large, the stone is called a conglomerate, or pudding stone; and when the cement is hard, and the pebbles entirely quartzy, the whole wearing into a rough surface, or when there are cells or empty spaces also ensuring a rough surface, the variety is useful for grinding, and becomes a *grindstone* or *millstone*. The finest of these latter are obtained from Yorkshire, France, and America, and have special uses; but they are different in no essential respect from the building-stones or flag-stones of which they form part. The best hard sandstones, splitting freely, and not used as grindstones, are greatly valued for pavements, and will be again alluded to when describing flags.

The building materials of this kind used in England are numerous, and include some of great value. From the carboniferous rocks at Craigleith, near Edinburgh, is obtained one of the best and most durable stones known. Its colour is lightish gray; its composition upwards of 98 per cent. silica, with 1 per cent. carbonate of lime, and a little carbon; its cementing medium is silica; its weight is moderate, amounting to 145 lbs. per cube foot; the quantity obtainable is indefinitely large, and it can be got in blocks of any required length and breadth, up to ten feet thick. It is worked in quarries, in which there are fifteen acres of stone laid bare, and fifteen more known to exist; the total depth of stone proved in the quarries being 250 feet. It takes upwards of 4000 lbs. on the square inch to crack, and nearly 8000 to crush a fair average sample; and exposed to disintegration by Brard's process, only three-fifths of a grain are lost. It has been greatly used in Edinburgh for all kinds of buildings. In London it is valued for steps and landings, and was employed in the repairs of Blackfriars Bridge. Its cost is moderate.

Other valuable sandstones in England are obtained from the millstone grit, also a part of the carboniferous series. Those quarried at Darley Dale, near Matlock, in Derbyshire, and in various parts of the same county, and in Yorkshire, are remarkably good, and much used. Samples of the first-named (Darley Dale) have been found to

resist pressure, under Bramah's press, to a remarkable extent, not cracking until the weight amounted to eleven tons on the square inch, and only crushing at fifteen tons. The millstone and coal grits are particularly valuable for grindstones and flags.

Some good stone is obtained from the new red sandstone, both in England and Scotland—especially the latter. The Storton quarries at Birkenhead, the Mansfield quarries in Nottinghamshire, and some others, yield a serviceable, cheap, and good-looking stone. In Scotland, that quarried upon Sir William Jardine's property, in Dumfriesshire, the celebrated Corn-Cockle Muir, is also of good and uniform texture, and of [illegible] tints. It has worn well where tried, and stands exposure to the atmosphere in that part of Scotland. Spedlings Castle, in 1508, and the present mansion of Jardine Hall, in 1814, were built of it; and the chiselled margins of the pillars and cornices of the latter, are still as sharp as when first carved. This stone can be furnished at a moderate rate, and in blocks of any size.

Excellent, hard, durable sandstones are obtained from the Wealden beds quarried at Tilgate, in Sussex; and the Kentish rag is a material well known, and remarkable for its durability under the worst exposure. This is from the beds of the lower greensand.

Limestones.—The limestones used as building material are chiefly from the carboniferous limestone and oolites, though the older rocks come into local use, and the chalk has been employed in the interior of some of our cathedrals for decorative work. The carboniferous limestone is so far altered by metamorphic action as to bear a polish and partake of the character of marble; and is, therefore, more frequently met with as an ornamental stone than for ordinary constructive purposes. The oolites thus remain as the principal sources of building stone; and being abundant, conveniently placed for carriage, easily worked, obtainable in large slabs of good colour, and generally durable, they are very widely employed throughout the middle and south of England, in all the principal towns, as well as in the metropolis. Of the whole number, the Bath and Portland oolites are the best known, and those which are most widely employed; but several others enter largely into use. The Northamptonshire oolites are better than those from Bath, and cheaper than the Portland stone; while the Oxfordshire stones, and those from adjacent counties, although extremely convenient, and much used locally, are of indifferent quality. The following are from English quarries, sold in London:—Anston stone; Bath stone, from Farleigh and Coombe, Down, Box and Corsham; and Portland stone, blocks, roach, &c., from Waycraft, Westcliff, and Bill quarries. Besides these, there are the Ketton and Barnack stones, both admirable in their way; and Ancaster (Lincolnshire), greatly used in some of the fine churches of the east of England. These are all, to a certain extent, laminated, having been deposited in beds; but they are so far changed or metamorphic as to have assumed a peculiar character, from which their name *oolite* is derived, from the Greek *ōon*, an egg, and *lithos*, a stone. They consist more or less completely of rounded particles, like the hard roe of a fish, mixed with shells and fragments of shells, often crystalline.

Bath stone varies a good deal in colour and quality; it is, however, usually of a warm cream tint, often streaked. It is fine grained, and very soft in the bed; but hardens when taken out of the quarry. On exposure to the weather in London and elsewhere in towns, it very rapidly injures, in consequence of the facility with which it absorbs moisture and impurities existing in the atmosphere. The composition on analysis shows about 94½ per cent. of carbonate of lime, with 2½ per cent. of carbonate

of magnesia, and no silica. It is capable of absorbing nearly one-third of its bulk of water ($2\frac{1}{2}$ gallons to the cubic foot). It weighs about 116lbs. to the cubic foot. It disintegrates to the extent of ten grains by Brard's process (as already described). It can be obtained in large blocks to almost any extent, at a cost of not more than sixpence per foot, cube, at the quarry; and in cohesive power it has been found that good specimens bear a pressure of 1,250lbs. before they crack, and do not break till they are subject to 1,500lbs. on the square inch. The advantages of Bath stone are numerous and manifest; but the objections to it are also serious. It appears rarely to have been subject to exposure without suffering severely; and in some cases the whole substance is disintegrated.

Portland offers a remarkable contrast to Bath stone in many respects, although both are oolitic limestones. The former is much whiter than the latter, much harder, and much stronger; but it is also heavier and dearer. Its colour is white, grayish white, and whitish brown. It consists of 95·2 per cent. carbonate of lime, and 1·2 per cent. carbonate of magnesia. It weighs 145lbs. to the cubic foot. It disintegrates only 2·7 grains under Brard's method; cracks at 2,000lbs.; and crushes at 4,000lbs. But its cost is very much greater than that of any kind of Bath stone; although for slabs, steps, landings, and other purposes where durability is important, it is often used. Of other stones, Ketton resembles Bath stone in composition; but it weathers very much less. It is about intermediate in weight between Bath and Portland; absorbs a good deal of water, and is extremely remarkable for its high cohesive power. Its disintegration is small. Barnack, with many resemblances to Ketton, is far less durable, as determined by Brard's process. It is more shelly in its composition, but has stood well in numerous buildings.

Those magnesian limestones which are valuable for building purposes consist of nearly equal parts of carbonate of lime and carbonate of magnesia, in a state of perfect combination and of crystalline texture. The colour is peculiar and agreeable, being accompanied by a singular pearly lustre. The specific gravity is high, the best stones weighing 150lbs. to the cubic foot. The cohesive power is very great, specimens of the stone cracking at 5,000 and crushing at 8,000lbs. to the square inch of surface. The price in London is moderate, and the stones of this kind work easily and are extremely durable. They are used for the exterior of the palace at Westminster.

Softer stones, and even chalk, are occasionally employed for internal work; but these are too easily injured to bear any amount of atmospheric exposure in our climate. Besides the materials commonly adopted for internal work in public buildings there are impure marbles, both from the oolite and Wealden series of rocks, formerly a good deal admired for small columns in gothic architecture. Of this kind are the Purbeck and Petworth marbles, and the Forest marble. They easily injure on exposure, and in time lose their polished surface, owing to the inequalities that exist in their composition.

The foreign building limestones used in England are few, but not unimportant. The best known are the even-grained, cream-coloured oolitic stones from the neighbourhood of Caen, in Normandy, formerly much employed in the construction of many of our cathedrals. These have always, and with reason, enjoyed a high reputation, and are considered the best material for internal use in the gothic buildings of the present day. The quarries of Allemagne (near Caen) yield a very good quality of this stone.

Granite.—The granites used in building are obtained from Cornwall and Scot-

land; but others, of excellent quality, exist in Wales; and even in Leicestershire, in the middle of England. Their use is confined chiefly to the more costly constructions, except in the immediate vicinity of the quarries, as the stone is far too hard to be easily chiselled into convenient forms, even of the simpler kinds. For ornamental purposes, and buildings richly decorated, it is rarely that this material is largely employed.

Many of the granites are, however, so remarkable for durability that they are used with great advantage for bridges, docks, piers, and public monuments. The large grained Cornish varieties used in London Bridge; the fine polished columns from Peterhead, near Aberdeen, in the King's Library, at the British Museum; many other interesting and excellent specimens in England; and the noble monuments of antiquity preserved in Egypt or transported to the museums of Europe—all serve to prove the applicability of granite for certain purposes. The porphyry vases of Sweden and Russia, and other ornamental objects manufactured in this material, may be regarded as proofs of successful ingenuity rather than illustrations of the real uses of the stone.

Marbles.—Various kinds of stone may be included under this general head. True marble consists of crystalline carbonate of lime, either almost pure, in which case the colour is white, or combined with oxide of iron and other impurities, communicating colour. Other substances are alabaster (sulphate of lime), serpentine (silicate of lime and magnesia), malachite (carbonate of copper), fluor spar, &c.

Marble, properly so called, is sometimes crystallized in a saccharoidal manner, having the fracture of loaf-sugar, or foliated, and with a peculiarly even grain. Such kinds are used by the sculptor, and are called statuary marbles. They are found in Greece (Parian marble), in Italy (Carrara marble), and occasionally in other countries of Europe; but in smaller quantities. They abound in some parts of India. The chief source of the present supply is from Carrara, in Tuscany.

The coloured marbles are far more common, and are infinitely varied in tint and in the mode of venation in which the colour chiefly appears. They are also very widely distributed in most countries where limestone occurs, in association with, or near to, those rocks technically called igneous or metamorphic—in fact, wherever crystalline forces have been at work. Thus, in our own country, the marbles of Derbyshire (black, gray, red, &c.) and of Devonshire are well known and belong to rocks of the older (Palæozoic) period, chiefly of the carboniferous series, and the rocks immediately underlying; the marbles of Ireland are not less beautiful and abundant, though less known. In Belgium, France (especially in the Pyrenees), Spain, Portugal, and many parts of Germany, in Turkey, Egypt, India, China, and other parts of the East, and in America, these decorative mineral substances are widely distributed; while Italy and Greece have been celebrated, from the earliest times, for the exquisite specimens of such material they have lavishly supplied to their intelligent and ingenious populations. The most celebrated and valuable of the ancient marbles are the rosso antico (red), nero antico (black), giallo antico (yellow), and verde antico (green). The red and green are not equalled by any now in use; but the black marble of Derbyshire and the Sienna marbles rival the black and yellow kinds. There is also in Derbyshire a small quantity of a very fine red marble.

Alabaster is widely distributed, though less so than marble. The best and most abundant supplies of the pure white varieties are from Italy, whence, also, are obtained some kinds streaked and tinted with brown, both much admired. Large quantities are found in Derbyshire, and in other parts of the middle of England; and the

neighbourhood of Paris is also well supplied. Owing to its softness and texture, alabaster is easily cut into any required form; but it does not harden by subsequent exposure, and can thus only be used where it is not subject to injury by atmospheric exposure. A singular limestone, having a warm yellow tint and considerable transparency, is found in Egypt, and is known as oriental alabaster. It is obtained in large blocks, and greatly valued. It was much used by the ancients, but has only recently become available to modern artists. A large vase of this material, remarkable for the elegance of its form and admirable finish, obtained a prize of the first class at the Great Exhibition of 1851.

Serpentine.—A material of remarkable beauty, capable of being made into ornaments, and used for church and house furniture, &c., is obtained chiefly from the Lizard Point, in Cornwall. It is a silicate of lime and magnesia, coloured with iron and chrome, moderately hard, but easily worked; and when properly selected, and employed for purposes for which it is adapted, few marbles can equal it. A Florentine serpentine (*ophite*) is much used, but possesses little of the richness of tint of that from Cornwall. The Irish Connemara marble is a variety of serpentine.

Malachite, a rich ore of copper, when found in abundance and in pieces of small size, is occasionally met with in large circular lumps of concentric structure, which, when cut into veneers, and properly joined, forms one of the richest and most valuable substances for decorative purposes. It is almost entirely from Russia, and chiefly from one mine in Siberia, that the malachite of commerce is obtained; although of late years, very good lumps have been brought from the rich Burra-Burra mines, near Adelaide, in Western Australia. The delicate green colour, varied by bands of deeper tint, and the extreme beauty of the texture and fineness of grain, give to this material a character and appearance altogether peculiar; while the costliness of the substance enforces the limitation of its use, especially for doors, chimney-pieces, tables, &c., to those whose means enable them to exhibit it to advantage. No one who saw the goods of this kind sent to the Great Exhibition of 1851, can forget the almost barbaric magnificence of the display; and some idea may be formed of the cost, when it is known that the value of the raw material is nearly one-fourth that of the same weight of pure silver, while a large loss of material, and great labour, is necessary to obtain the veneers, and so apply them that the pattern shall be pleasing and satisfactory.*

Spars are occasionally employed for the construction of ornamental vases and other objects of luxury. Fluor spar, or Blue John (fluate of lime), is found in large pieces in Derbyshire, and is especially esteemed for this purpose. It is a beautiful material of rich blue colour, and great transparency. The colour is frequently modified by a partial burning.

Slates, Slabs, and Flagstones.—Slates and slate slabs are argillaceous rocks in a peculiar state of partial crystallization, possessed of the property of cleavage, or splitting in some one direction quite independently of the original bedding. Other slabs and flagstones are usually silicious rock, combined with more or less argillaceous or calcareous matter, and splitting into tabular masses of various size and thickness in the original planes of bedding or stratification. The best slates are obtained from various parts of North Wales, near the coast; from Delabole, Tintagel, and elsewhere on the north coast of

* See Jury Reports, p. 569, *et seq.* The value of malachite, in a manufactured state, is about three guineas per pound avoirdupois, and the square foot super of finished veneered work contains about two pounds and a half of the mineral.

Cornwall; from various parts of Cumberland; and from the west coast of Scotland, generally from quarries of great magnitude. The best slate slabs are from Wales. The finest slabs and flagstones (not argillaceous) are from Yorkshire and Caithness; but some of the Portland stones (limestones) of the best quality are preferred for internal use, as for steps and landings. Excellent foreign slates are obtained in France, chiefly from near Angers, and in Brittany; in Belgium from the Ardennes; in western Germany from the Duchy of Nassau, and in the east of Europe from other places. Slates and slabs are also found in America.

It is not usually the case to find slates and slabs in good condition near the surface, where long exposure to the weather has usually disintegrated, and even destroyed the texture, and often, by partial hardening, obliterated or obscured the cleavage. As it is, however, entirely from the superficial rock and its geological condition that a judgment must be formed, a certain amount of experience, combined with a knowledge of the material, enable the geologist to judge well of the chance of a valuable quarry. Uniformity of texture and condition of the rock for considerable distances, the nature and condition of the cleavage, the direction of the cleavage planes, the nature of the small veins of other material pervading the slate (of which there are always many), the presence or absence of iron pyrites, the direction and magnitude of the joints—these are the chief points concerning which careful investigation is necessary. But any or all of these are altogether insufficient to communicate a market value to a property unless the essential point of cheap and ready conveyance to a large market can be secured, and the quarries are so situated that the waste can be disposed of, and the valuable part of the slate laid bare without great expense.

There are varieties of colour, of texture, and of hardness, which affect the value of slates. The common colours are green and purple, both of which may be good. The hardness should be considerable, without interfering with the fissile character of the material, and the grain should be fine. If large slates or slabs can be cut, this of course adds greatly to the value of the quarry.

The slate quarries in various parts of England, Wales, and Scotland, are objects of great interest, if only in a picturesque point of view; but they are of a magnitude really important in an economic sense. The Delabole quarry, for example, in Cornwall, is opened for some hundred yards in length, and has a width of upwards of a hundred yards, and a depth nearly as considerable. The Ballahulish quarries, in Scotland, are worked in three terraces facing the west, the total height of the workings being two hundred and sixteen feet. The annual produce of slates is from five to seven millions of all sizes (ten thousand tons); and the quantity of waste cannot be less than fifty millions of tons.

But the great Penrhyn quarry, close to which are the Llanberris quarries, and others, are far more remarkable and valuable; in the Bangor quarry, in the extreme west of Carnarvonshire, the band of slate (or vein, as it is locally called) is considered to run twenty miles, with a breadth of five hundred yards. Where long exposed, the slate is usually much harder than is convenient or profitable to work, and the valleys yield the best and most profitable portions. The one quarry of Penryhn, belonging to Col. Pennant, has been opened nearly a century, and is worked in twelve galleries of horse-shoe form, one above another. Each gallery is forty feet high, the highest being five hundred feet above the lowest; but the uppermost slates are of inferior quality. Upwards of three thousand men are employed here, and the daily make exceeds five hundred tons. The other quarries, though smaller and less profitable, are of great value and importance.

Flagstones.—Of the slabs and flags used for paving, cisterns, and various other purposes, those from Festiniog (North Wales) are remarkable for their large size, even grain, and great beauty. Those from Valencia (west coast of Ireland) are also extremely large, and of excellent quality.

The Yorkshire flags are fine-grained laminated sandstones, from the millstone grit formation, cleaving into slabs of large size, whose thickness is from two or three, up to eight inches. They are remarkable for their extreme hardness and toughness. Of the beds yielding these flags, there are no less than fifty well known, and these are worked in upwards of a hundred quarries around the towns of Leeds, Bradford, Wakefield, and Halifax. The Caithness flags are from the much older beds of the old red sandstone, and are dark coloured bituminous schists, slightly micaceous and calcareous. They, like the Yorkshire stones, are valuable from their great toughness and durability. They are not obtained in slabs so large as those found in Yorkshire.

The limestones of the carboniferous and even of the silurian period yield some good flags; and a remarkable fissile bed of the lower oolitic series is locally much used for slating, under the name of Stonesfield slate, and Colley Weston slate. Coarse, easily splitting limestones are extensively quarried in Oxfordshire, Northamptonshire, and some adjacent counties, and are of some value where slates are costly.

ROAD-MAKING AND ROAD MATERIAL.

This department of engineering requires a knowledge of geology and of the structure of the earth, not merely in the selection of fit material, but also in the original laying-out of the line to be adopted, whether for ordinary roads or for rails. In the former case, indeed, local circumstances have usually entered almost entirely into consideration, and except in the colonies, and in India, there is little opportunity of exercising engineering skill in this department; but in all cases of new lines being constructed, especially where great works are required, the possession of geological skill is of the highest importance to the engineer as well as the contractor. This is more easily recognized in the case of heavy cuttings through doubtful material than in any other way; and we need only point to the slopes on the London and Brighton railway at New Cross, or of the London and North Western near the Euston Station, as illustrations of the influence of the London clay on the cost of portions of road at one time thought little likely to be troublesome. The Box tunnel on the Great Western line, that near Rugby on the North-Western, and some on the great lines in the manufacturing districts of Lancashire and Yorkshire, all afford examples of the same kind.

The chief points in which a knowledge of geology is useful in road-making are, first, in the selection of the line, which should have a naturally sound foundation of rock, well drained, and not liable to destruction from mere exposure; secondly, in the direction of the cuttings, which should have distinct reference to the dip of the strata, as well as with regard to the slopes, and the probable cost of such works; and thirdly, in cases of tunnels, both as to the material to be cut through and the probable intersection of wet beds. The first of these requires little more than a reference to the superficial deposits on the outcrops of the beds, and will need little special information on the details of the science. The position of cuttings, as regards their slopes and drainage, and security from subsequent slips, is, however, more directly dependent on structure, and is more important. Thus it will be found, that where the cutting is in the direction of the strike of the beds, there will be more tendency to slip on one side than on the other, except where the stratification is perfectly horizontal. The best direction for

a cutting is at right angles to the strike; but this is not always possible, and it is well to know that where the beds dip, and some that are permeable are to be cut through, particular care should be taken to prevent the surface drainage from passing into or over the permeable bed at its crop. This prevented, the beds may remain firm in their places; but, otherwise, they will sooner or later slip, and become very troublesome.

The position of strata is often extremely important in determining the possibility, not only of avoiding slips, but of tunnelling or sinking shafts without enormous expenditure. Thus, in some cases, the presence of hard igneous rock is determinable by surface phenomena well understood by geologists, though not immediately recognised without a knowledge of the earth's structure. The cost of large operations of tunnelling is enormously affected by such occurrences. In tunnelling through wet strata, there are also some cases where the position of the strata is such as to render the presence of large quantities of water probable; and sometimes it happens that such water can be partially or entirely cut off by surface operations before the tunnelling is commenced. There have been many instances in which extensive tunnels have ruined the contractor for the want of a little application of geological knowledge.

The material for roads will necessarily depend on local circumstances, although, where there is a very rapid wear, it is hardly too much to say that the best materials will be the cheapest. The chief quality for a good road-stuff is hardness, combined with toughness, and a texture sufficiently uneven to ensure a rough surface under wear. There are certain stones, such as Penmaenmawr, which are exceedingly hard and of fine grain, and have a certain value in some cases; but as they necessarily wear smooth, they are ill adapted for cities exposed to alternations of wet and dry, cold and heat. Granites are for this much superior, though less durable; as, owing to their composition, which includes two sets of crystals of different hardness (quartz and felspar), they always have a tendency to retain a rough surface, giving foot-hold for horses. Those basalts which do not readily decompose are perhaps equal in value to granite. It may be said, in a general way, that all stones of uniform texture, composed of one ingredient, are unfit for roads of the first class. Thus limestone of all kinds is inadmissible on this ground, even if it were not too soft and too readily worn into dust and mud. Flints, which from their hardness would seem valuable, are really unadvisable for want of some cause of roughness. It will, however, be easily understood, that for country roads any hard material, that does not soon work up into mud or grind into dust, and that has the advantage of requiring no expensive carriage, will be selected. It is well to remember, in such cases, that sandstone is better than limestone, and hard limestone better than slate; while basalts and granites are exceedigly good or exceedingly bad, according to the proportion of alkaline earths (especially soda) which they contain.

BRICK AND PORCELAIN CLAYS, CEMENTS, AND ARTIFICIAL STONE.

There are many materials used in construction that require previous preparation and moulding, and sometimes burning; and are made to assume their intended form by some mechanical means distinct from cutting and squaring in the quarry and workshop. The most important of these, in respect to the extent of its usefulness, is, beyond all doubt, common brick clay, and those varieties of clay which resist high heat. Mortar, and various cements, sometimes used to attach together other stones, but occasionally moulded and used as stone, next require consideration; while the finer clays worked

by the porcelain manufacturer and potter, if inferior to these, are so rather in the magnitude of the objects manufactured than in the value of the fabric.

Brick Clay, of the better kind, consists of a tolerably pure silicate of alumina, combined with sand in various proportions, and free from lime and other alkaline ingredients, of which there ought not to be more than two per cent. The relative percentages of silica and alumina do not seem extremely important; and there is always a variable proportion of water present, which is also of little consequence. It is clear that for use, the clay must be tolerably free from large stones and coarse particles; and, as the principal process of manufacture before burning consists in mixing the clay with water and sand, or ashes, to a uniform consistency, anything that would interfere with this process is injurious.

A certain proportion of iron is commonly present; and this, when the brick is burnt, usually passes into the state of peroxide, and gives the brick a dark red colour. The annual consumption of bricks is very large. In this country it amounts to twelve hundred millions, and the clays are obtained from various geological formations.

Fire Clays.—These owe their peculiar properties to the almost entire absence of alkaline earths, and of any such quantity of iron oxide that it could serve as a flux. Many excellent clays of this kind are found in the coal formation both in the British islands and abroad. The best are those of Stourbridge (Worcestershire), some near Newcastle-on-Tyne, and some near Glasgow; others of good quality are obtained in Belgium and France. The Stourbridge clay is found in a bed about four feet thick, and consists, according to an old analysis by Berthier, of 63·70 per cent. silica, 22·70 alumina, and 2 oxide of iron, the rest being water.* One of the clays much approved of in Scotland contains 65·20 silica, 33·41 alumina, ·32 lime, ·13 magnesia, ·49 iron oxide, and ·45 of various phosphates. All the fire clays are greatly improved by exposure to weather before use. In some cases this is continued for years.

Porcelain Clays are of various kinds; but the best being derived from the decomposition of the felspathic portion of granite, consist of nearly pure silicate of alumina (silica 60, alumina 40). Very large quantities are obtained in Cornwall and Devonshire—nearly ten thousand tons of the finest, and about three times as much of the commoner kinds, being annually exported to our own potteries in the North Staffordshire coal-field.

The manufacture of porcelain and pottery is an art that does not properly come under consideration in the present treatise; and it is only necessary to observe here that there are no known sources of supply of the raw material of the better kind, except those which may be traced to the decomposition of granite.

Cements.—These are of various kinds, extremely distinct, and having different bases. The one kind, depending for its peculiar properties on sulphate of lime, with which it is made, may be conveniently designated as *plasters;* the other, in which carbonate of lime is the essential combining substance, includes mortar and hydraulic limes, and for this the name *cement* may be adopted. We may first consider the cements as being the material of greatest importance in manufactures.

The commonest of all cements used to attach bricks to each other is called *mortar*,

* Analyses of clays must necessarily be mere approximations, as the quality of the clay differs much in different samples, even when carefully prepared. It must also be remembered that, till very recently, the alkaline earths, and many other substances, were not determinable by ordinary analysis, and frequently escaped notice.

and is prepared by first making *quicklime* (which is done by calcining chalk or limestone in a kiln until it becomes decomposed, parting with its carbonic acid gas, and passing into the state of a white or gray powdery material, greedily absorbing water with the evolution of much heat), and then making a paste by mixing the quicklime with sufficient water, and about two or three times it own weight of sharp sand or gravel. This mixture dries slowly, but when dry becomes extremely hard, and firmly attaches itself to the foreign substances in contact with which it is placed. When a layer of it is placed between bricks or stone, it cements them firmly together.

It is often desirable to obtain a cement that shall dry more rapidly than common mortar, and under less favourable circumstances for dryness; and it is found that when a certain proportion of clay has been present, mixed with the limestone before burning, (whether naturally or by preparation), and the calcination is carefully conducted, and not carried too far, the resulting lime, when mixed with a proper quantity of water, sets rapidly in a damp atmosphere, and even under water. Such a limestone is found in the lias, in the London clay, and in various other rocks; and the resulting lime is called *hydraulic lime* or *hydraulic cement*. The simplest and strongest of such cements is obtained when from 10 to 25 per cent. of the stone consists of silicate of alumina, and the rest is carbonate of lime. The larger the proportion of clay in the stone *cæteris paribus*, the more rapidly the cement becomes solid, the hardening being complete in two or three days, when the proportion amounts to 25 per cent., and taking three weeks when only 10 per cent. Much depends (especially in artificial admixtures) on the minute division and perfect admixture of the foreign particles.

The kind of cement known as *Roman*, or *Parker's*, is made from nodules of calcareous matter obtained from the beds of the London clay at Sheppey and Harwich, from the Oxford and Kimmeridge clays near Weymouth, from the lias of Whitby, and from similar deposits elsewhere. In all these cases the admixture of clay with the carbonate of lime is natural, and varies considerably in different samples. *Medina*, *Atkinson's*, and *Mulgrave*, are names given to cements of this kind, offering no essential difference in their nature.

Portland Cement is made from carbonate of lime, mixed with great care, in definite proportions, with the muddy deposits of rivers running over clay and chalk. The whole of the materials are carefully pounded together under water, and are afterwards dried and burnt. From various experiments, it appears that when well made, in good condition, and properly used, the value of Portland cement is much greater than that of the natural kinds (Roman); but in practice on a large scale, different casks, even from the same maker, and made at the same time, vary so much, that it is not safe to trust it to a much greater strain than would be given to Roman.* It is not unusual, in making use of these cements as artificial stones, to introduce large quantities of broken stone and brick, thus making the material a kind of concrete. Portland cement is said to make an admirable concrete when mixed with about ten or twelve times its weight of broken stones or pebbles. The name Portland is given from the slight resemblance in colour shown by this cement to the stone so called. The colour of Roman cement, on the other hand, is nearly brown, sometimes dark brown.

* Good Roman cement will bear a strain of nearly 60 lbs. to the square inch, but some specimens will break with 20 lbs. Good Portland appears to bear more than twice the strain of good Roman. The measure of the strength is the weight that will drag asunder two bricks or slabs cemented together by the different cements tried.

Plasters.—Gypsum or alabaster (sulphate of lime) when calcined is not decomposed as common limestone is, by parting with its carbonic acid, but simply loses its water of solidification. It is then reduced to a white powder; and when this is again mixed with water, a certain portion is absorbed, a partial crystallization takes place, and the mass becomes once more solid, though not so hard as before. The powder is called Plaster of Paris. When mixed with thin glue instead of pure water, it forms *stucco;* and both as common plaster and stucco it enters largely into use for various purposes.

If, instead of being used with water, plaster of Paris in fine powder is thrown into a vessel containing a saturated solution of alum, borax, or sulphate of potash, and after soaking for some time is taken out, re-baked, once more reduced to powder, and then moistened with a solution of alum, instead of pure water, before use, a hard plaster is obtained, known by various names, but essentially of the same nature. This is now much used in the interior of houses, and takes a fine polish. *Keene's cement* is made with alum, *Parian* with borax, and *Martin's* with pearlash.

Most of the plaster of Paris used in England is obtained from Derbyshire, Nottinghamshire, and Cumberland, from the new red sandstone, and beds of the oolitic period. A small admixture of impurity, whether lime or silica, appears to be of no material disadvantage.

Artificial Stones.—An admirable and useful artificial stone is made at Ipswich, under a patent taken out by Mr. Frederick Ransome, and is now entering largely into use for filtering-slabs, chimney-pieces, vases, and decorative architectural work of all kinds. It consists of sand moulded with a fluid silicate of potash, and afterwards baked in a kiln. The fluid silicate is obtained by exposing flints to the action of caustic alkali in a steam boiler at a high temperature. The subsequent burning changes the fluid silicate into a glass; so that the goods, when completed, consist of nothing more than the particles of sand cemented together by this glass, and are altogether unchangeable by ordinary exposure to damp and frost.

The other artificial stones in common use are composed of fire-clays of various kinds, and are more properly called *terra cottas.* They all contract greatly in burning, and in this respect are far inferior to Ransome's stone, above described, which, from its nature, suffers no contraction, and scarcely any alteration of form in the kiln. The best terra cottas (kiln burnt) are made in France, and the manufacture has there obtained a high state of perfection. Various attempts in England have met with partial success; but the unequal contraction of the material is a difficulty rarely surmounted. The best clay used for this purpose is the purest fire-clay.

THE GEOLOGY OF MINERAL FUEL.

In treating this part of our subject, it will be well to begin with some account of fuel generally, and the sources of supply of this most important substance. The process of combustion being simply the rapid combination of certain substances with oxygen, with the evolution of heat, it is clear that, although mineral fuel alone is that commonly employed at the present day in our own country on a large scale, there are numerous substitutes concerning many of which natural history has to deal.

Of all these substances, wood, peat, and coal are in daily use, and best answer the required conditions; but it may be quite as well to know that, under other conditions, other substances altogether different might be employed. The greediness with which some metals (for example, potassium and sodium, the bases of potash and soda)

attract oxygen is so remarkable, and the quantity of heat evolved so great, that when thrown into water, the water is rapidly decomposed, and these metals burn with the most extraordinary vehemence. Other illustrations, having the same object, are not unfrequently shown by the chemist; and it is certain that in this case, as in many others in which certain arrangements seem to us absolutely essential to the existence of life, and really are so, as far as our experience of life extends, are by no means necessary, and probably may not be universal. Many very large and important bodies in the universe may undoubtedly be so totally unlike our earth, in what seems to us its most essential characteristics, that we must give up at once and for ever the hope of understanding the state of existence of organic being in such bodies, and must assume that the arrangements so necessary for us, so varied and ingenious in their character, and so perfectly adapted for their purpose, form but one series out of an infinite group of adaptations, concerning the nature, object, and extent of which it would be equally foolish and impossible to speculate with the knowledge we can hope to obtain on this earth. Thus it must always remain altogether conjectural in what way the sun is a source of heat to the various planets, satellites, and comets of our solar system.

It will be understood then, that for all the various occasions on which fire is required on this earth, a certain consumption of fuel is necessary; and that, in some shape, carbon is the essential ingredient in supplying this, as well as many of the wants of man. Pure carbon exists as a mineral in no less than three totally distinct states; first as diamond, crystallized, extremely hard, and in excessively small quantity; as graphite or black lead, also partly crystallized, but in a different way, very soft, and moderately abundant; and lastly as anthracite, not crystallized, but found in large or small masses, and sufficiently abundant to be a very useful and valuable fuel. Mixed with more or less hydrogen and a little ash, this same elementary substance appears plentifully distributed in some limited districts, where it is known under the general name of coal; while in a still less pure state, but also as the chief ingredient, we find it forming the essential portion in all vegetable substances, as well as in those accumulations of trees and moss which are known in various parts of the world, and are called by us peat-turf, moss, bog, &c., lignite, and brown coal.

The Stores of Fuel.—It has been intimated that the chief sources of fuel are either those stores of carbon secreted by the vegetable kingdom, and consisting of the woody part of trees; those accumulated heaps of vegetable matter which have escaped decay or combustion, and become bedded in large masses in peat bogs; and those greatly altered accumulations—still, however, of vegetable origin—which, as coal, form in some places very extensive and thick beds, capable of being extracted with infinite advantage to man.

A forest of trees, extending over a wide tract of country, is undoubtedly a very important and useful store of fuel. Making a calculation of a very rough kind, it would appear that a square mile of forest land, covered by twenty thousand trees, each containing on an average two cubic yards of solid fire-wood, would be equivalent to about an acre of coal six feet thick (ten thousand tons weight), or to three acres of turf of the same thickness (two yards). In tropical countries there are many thousands of square miles thus covered with forest; in damp temperate climates there are thousands of acres of turf; and in various districts are thousands of acres also of coal—the thickness being often far greater than has been estimated, even on an average of extensive districts. Now, when we consider that a ton of coal will, on an average, evaporate

nearly fifteen hundred gallons of water, and that six gallons of water evaporated in an hour is the equivalent to a horse-power, the practical bearing of this way of regarding the subject will be recognised, and the resources of fuel understood.

It is not in England, nor even in the noble and extensive forest-districts of central or northern Europe, that we must look for the development of vegetable life on a large scale. In many places, indeed, such forests may be seen as those we have estimated above; but there are other districts—sources of fuel—which are far more remarkable. That region which occupies the great river-basins of the Orinoco and the Amazon, in South America, is perhaps the most marvellous, and is well worthy of notice. It has been described by Humboldt as so truly impenetrable, that it is impossible to clear with an axe, for more than a few paces, any passage between trees of eight or twelve feet in diameter. The area of this district is about twelve times that of all Germany. Throughout there seems to be hardly any space not occupied by woody vegetation; for the intervals between the trees are filled up by an undergrowth of plants, forming a compact wall, only intersected by the rivers and a few paths made by the larger carnivorous animals from the interior to the water-side. In one place we are told, where the river had narrowed to about three hundred yards, it flowed in a perfectly straight line, enclosed on each side by dense wood. "The margin of the forest presents at this part a singular appearance. In front of the almost impenetrable wall of giant trunks of trees there rises from the sandy beach of the river, with the greatest regularity, a low hedge only four feet high, consisting of small shrubs. Some slender thorny palms stand next, and the whole resembles a close well-pruned garden hedge, having only occasional openings at considerable distances from each other, doubtless made by the larger quadrupeds to gain easy access to the river. When startled, these animals do not attempt to break through the hedge, but walk along between the river and the hedge until they have reached the nearest opening, when they disappear through it."

It may interest some readers to know the equivalent of this amount of vegetation in coal. Taking the area of this district at two millions of square miles (two-thirds of that assumed by Humboldt), and the average height of the vegetation thirty feet, we cannot estimate the whole quantity of vegetable matter existing at any one time on the surface at less than thirty millions of millions of cubic yards (or tons). In actual fuel, such as coal, this would probably not be available to the extent of more than one-third part—say ten millions of millions of tons of coal. Now this may be regarded as about a hundred times the quantity present in the South Welsh coal-field, an area of nearly a thousand square miles. It appears, hence, that the quantity of coal, deposited in a limited area in the temperate zone, not remarkable for thick vegetation, is twenty times greater than the whole quantity of vegetation that could grow upon that space at one time under the most favourable circumstances that can be imagined in tropical climates. It should be remembered, in making such calculations, that wherever nature is thus prolific in providing vast stores of any kind, she is equally careful to provide means for their removal by various causes of decay acting with a rapidity utterly unknown amongst us. The ants of the tropics will empty a tree in a few hours, leaving only the bark.

It is well to know something of the vast amount of vegetable matter in the tropics, that we may conjecture the rapidity with which it may occasionally be heaped together into masses indestructible by ordinary exposure; but living nature is constantly in course of change, and but a very small part of what exists at any one time

is permanently retained in anything like the same shape. Thus in these forests when a tree dies it soon becomes a prey to insects which devour the last fragment of woody fibre; and these, again, form the food of larger animals. The carbon thus enters into new arrangements and performs a lengthened course, only at intervals; and by accident, as it were, becomes fixed, but then rarely in the form of peat or coal available for fuel.

The value of wood is, however, extremely great, as in many parts of the world no other fuel can be obtained, except at such cost as to render it practically useless. It is generally estimated that one pound of green wood will evaporate about five pounds of water, a pound of dry wood seven pounds, and a pound of pure charcoal fourteen pounds. Wood always retains a certain portion of water, generally as much as 20 per cent., even when air-dried. It consists of about 50 per cent. or one-half carbon, and from 42 to 45 per cent. oxygen, the rest being hydrogen and earthy matter, chiefly potash, soda, lime, silica, and iron.

Wood is either used in a natural or partially dried state, in which case there is considerable loss from the quantity of water actually present and the additional quantity produced by the hydrogen and oxygen during combustion, or else in a charred state, the volatile and combustible ingredients being driven off by burning in a close vessel or chamber. By burning in partially open heaps, from 14 to 16 per cent. of charcoal is obtained from green wood, but, when charred in close ovens or retorts, upwards of 25 per cent. can be produced. The advantage of the latter process will appear by comparing these results with the relative values of the different fuels, as given above. Thus 100 lbs. of green wood evaporate 500 lbs. of water. Reduced to charcoal by the heating in ovens, the quantity of fuel would be reduced to 25 lbs.; but the water evaporated would be fourteen times this quantity, or 350 lbs. It is evident that the reduction to charcoal involves a certain loss of fuel in all cases; but, on the other hand, a considerable advantage is gained for many purposes, owing to the increased value of the fuel and diminished cost of transport; since about 36 lbs. of charcoal, once made, are capable of evaporating as much water as 100 lbs. of wood, while they do not occupy one-third of the space. The cost of transport is thus much less considerable, and the advantage of reducing the wood to charcoal is easily seen. Of common woods, oak and pine are the most valuable.

The time required for the full growth of forest wood for fuel varies naturally in different climates, and according to the prevalent species of trees. Not more than two per cent. of the actual quantity of well-grown wood existing at a given time, in a given space, can be regarded as annually available. Most parts of the world, however, will be found to possess a large quantity of timber within a reasonable distance, until civilization has so far advanced as to limit the range of forest land, and check the natural increase. After this, the only fit source of fuel is either from peat-bogs or from the mineral kingdom, in some shape or other.

The simplest and least altered vegetation, embedded in accumulated masses within the earth or lying on its surface, is that found in low and damp situations, where water is easily retained at the surface for want of natural drainage, where aquatic or marsh plants abound, and where trees are occasionally buried in rapidly-growing bogs. Such masses are called

Peat, or Turf-bogs.—Near the surface the layers of vegetable matter (*turf*) are generally light, spongy, and manifestly of vegetable origin. Deeper in the bed the texture is more compact, the colour darker, the vegetable character scarcely, if at all

recognizable, and the ash in larger proportion. Under this form, and under the name *peat*, the weight of the cubic foot is nearly double that of turf, but the quality is not improved. The ash which remains after burning varies from 15 to 30 per cent., and there is generally a large proportion of water present, even when the peat has been well air-dried, so that the heating power does not exceed two-fifths that of coal. After deducting the ash and coal, there still remains less than 60 per cent. of carbon in ordinary peat, the rest being oxygen, nitrogen, and hydrogen gases.

In some countries, and within certain limits of climate, the growth of peat bogs is extremely rapid, and the extent of surface thus covered enormously great. But these limits are well marked; and although within their range the quantity of fuel thus obtainable is extremely large, its quality is somewhat inferior, and the cost of transit, even to very short distances, renders it scarcely possible to use it extensively. Various methods have been tried, from time to time, to dry and compress the peat, to render it compact and more combustible by soaking with tar, and to render it more available by charring. The success of such methods is at present imperfect. Most of the compressed peats still contain too large a per centage of ash and water, and the charcoal is of too loose a texture, and too bulky, to answer the requirements of a first-rate fuel. But the charcoal, although too light for fuel, except when the turf has first been compressed, is very valuable in the manufacture of gunpowder, for various sanitary purposes, and for manure, while the products obtained in its formation (when the charring is performed in a close vessel), are of considerable value. The finest peat-cokes are generally obtained from the light open turfs obtained from near the surface of a bog.

Ireland, Holland, and some parts of Germany, are remarkable for the large extent of surface at the present time occupied by bog. In the former country nearly one-seventh of the whole island is thus covered, and the depth varies from a few feet to thirteen or fourteen yards, being much greater even than that in particular spots. In various other parts of Europe vast deposits of similar kinds occur, and the economical employment of peat fuel is a matter whose importance it would be impossible to exaggerate. The turf, as usually obtained, yields nearly 75 per cent. of volatile matter, and from 2 to 10 per cent. of ash; although sometimes much more. The qualities vary extremely in different bogs, and would probably require different treatment to render them economically available. From some recent experiments, by Sir R. Kane, it seems likely that, in particular cases, the value of the products is so considerable as to justify an elaborate, and even costly, mode of treatment, at least in the way of experiment.

Lignite.—In many parts of Europe, and even in the British Islands, there are found large accumulations of partly altered vegetable matter, known sometimes as *lignite*, and sometimes called *brown-coal*. This substance is hard, compact, and comparatively heavy; and often retains its woody texture, although some portions, almost crystalline, and of a fine black colour, form an impure variety of jet. Jet itself is found under somewhat similar circumstances. On being heated, lignite often burns with difficulty and with a disagreeable odour, and is found to contain some water and a good deal of ash. The available proportion of carbon varies from 50 to 70 per cent.; but this cannot readily be obtained in a convenient state by charring, owing to the mechanical state of the carbon in the mineral, and the volatile products are rarely separated with advantage.

The chief deposits of lignite are met with in central Europe, in or near the basins of the principal rivers. In some cases their mass is enormously great; but in linear extent they are nowhere so considerable as the peat bogs, and are equally unlike

the regular coal bands. But little use has hitherto been made of these beds on a large scale and for manufacturing purposes; although for household fuel they have, for some years, entered into ordinary consumption in Styria, and in the Duchy of Nassau. They have been employed in England for pottery works, but are of little importance.

Coal is, at present, the only really valuable and available source of fuel on a large scale, for important and extensive operations. It is far superior to wood as a combustible, being nearly equal in this respect to pure charcoal. The finer kinds contain but little ash. Some varieties are valuable for their volatile products, yielding large quantities of gas for lighting, and much tar, besides various useful substances; others consist of almost pure carbon; while others, again, contain such an admixture of volatile and inflammable ingredients that the coal readily takes fire, burning with much heat and great steadiness. A hundred pounds weight of coal occupying, when solid, about one and a half cubic feet, will evaporate, when perfectly consumed, as much as 1,200lbs. of water from the boiling point. The same volume of oak charcoal would weigh less than 12lbs., and only evaporate about 150lbs. of water. The same volume of solid wood, well dried, would weigh about 45lbs., and evaporate 270lbs. of water. The same volume of light turf would weigh about 30lbs., and evaporate 340 lbs. of water; while this quantity of good lignite, though weighing as much as 110lbs., would still only evaporate 800lbs. of water. This mode of estimating by space is of the most practical kind, as the cost of transport depends on the facility of packing a large quantity on a truck or in the hold of a vessel; and the value of coal is thus seen to be very considerably greater than that of any other fuel, the original cost of obtaining being assumed as equal.* Practically also it is found that where it exists in thick beds, the working expenses in getting coal are smaller than for other fuels.

Although coal is very widely spread over the earth, and exists in some districts in enormous quantities, these are still so limited, and their value depends so much on geographical position, that the actual use of the mineral, as a fuel, is greatly limited. The several well-known coal-bearing districts in our own islands need only be referred to generally as among the most valuable in the world for position, available quantity, and excellence. On the east side of England we have the great Northumberland and Durham coal field, with half a million of acres of workable coal, approachable in various places along an extensive coast line with several good ports, admitting of the best and cheapest transport. In South Wales there exists a yet larger area, in which thicker and equally valuable beds can be worked; and there, also, the coast presents a number of convenient ports from which the coal can be shipped. In the interior, a vast tract in Yorkshire, Lancashire, Derbyshire, Staffordshire, and Shropshire, larger in extent than the other two districts together, is not only adapted to supply the interior of England, but, by means of railroads, competes successfully in the metropolis even with the better coal conveyed by sea from the north. In Scotland, the valley of the Clyde is equally rich, and scarcely less important; while in Ireland each province possesses coal areas, which are, indeed, now but little worked, but which may hereafter prove of great value. On the continent, Belgium is especially rich; France and Germany possess stores of mineral fuel, the former especially, of considerable extent, though placed far in the interior; Spain has large and excellent beds, those in the

* The form and size of the separate fragments or blocks in which the fuel can be obtained manifestly affects this calculation. Those fuels that pack most closely thus possess an advantage which must be taken into consideration.

Asturias not unfavourably placed for present use; while Russia is provided with this, in addition to her many other sources of wealth. In various parts of Asia the existence of coal is well known; but the details are not yet sufficiently reported to enable us to judge as to the extent of resources of this kind actually to be depended on. Several remarkable and important coal fields are known in India, and within a very short period the stores of this mineral on the shores of the Black Sea are likely to come into active use.

Rich and favoured as England and the old world have proved to be in mineral fuel, North America is far richer, and its future promises yet grander results. Making a liberal deduction for unproductive portions of the fields, we cannot estimate the area of available coal as less than twenty-five millions of acres in the United States, and ten millions elsewhere. If, however, we assume, as a very rough approximation, that there are in all fifty millions of acres of coal-bearing beds on the earth's surface, and that their average thickness is ten yards, and if we take the present consumption throughout the world at fifty millions of tons per annum, it will appear, from a very simple calculation, that there exists a supply at least equivalent to the consumption of fifty thousand years at the present rate. We need hardly trouble ourselves at present, therefore, with any alarm for the future, even if many new uses and applications of fuel should be discovered, without the corresponding discovery of new sources of fuel.

Like wood, peat, and lignite, coal usually contains a certain proportion of inflammable and bituminous ingredients, which it is sometimes desirable to remove before using the fuel. For this purpose the coal is burnt into *coke*, either in heaps, or more usually in ovens constructed for the purpose, each holding about two tons of coal. The result is a very hard brittle mass, very dense, and of a steel gray colour. A quantity varying from 10 to as much as 50 per cent. of the weight of coal is lost by coking; and the value of coke as fuel is about one-fifth greater than that of an equal weight of the coal from which it was made.

Having now passed in review the various kinds of fuel used for ordinary heating purposes, and having seen that of all these coal is the most valuable, and the best adapted for general use, we shall find it interesting to consider more closely the exact nature of this substance, and the circumstances under which it appears to have been formed. Presented, as we know, amongst the earths, and clays, and stones that make up the external film or crust of the earth, formed manifestly under very similar circumstances, and in association with water, proved both by its own texture and structure, and by the frequent presence of leaves and trunks of trees, to be very closely connected with the vegetable kingdom, there now remains no doubt, in the minds of observers, that this mineral fuel is nothing more than a modification of what is still so abundant, and so rapidly multiplied—the pleasant green covering of the earth, the herbs of the field, the trees of the forest, or the rank, luxuriant growth of the swamp. It is to these, and these only, that we owe the stores of brilliant black stone which are more valuable for England than many Californias or Australias. To these we are indebted for the means of rendering available our ores of iron, our copper and lead ores, and our position for trade and manufactures of all kinds, which together are the sources of our national greatness; and therefore it is well to go back a little, to seek out the history of the tribes of plants that once grew in these latitudes, whose remains have been handed down from generation to generation, and which still exist, to help us to the solution of some of the most singular and difficult problems in natural history.

Something has been already said on this subject (see p. 86), but some further remarks suggest themselves.

Of all the plants which clothed and decorated our land at the time of the deposit of these large accumulations, since converted into coal, only a very few species seem to have been retained in such form as to admit of their being now made out satisfactorily. At least, we are bound to assume this from the limits within which the various specimens are confined, including as they do only the leaves (fronds) of ferns, in a very imperfect and mutilated state; detached trunks and roots, in which it is doubtful whether we really see the external surface or not; a few cones and nuts, and still fewer fragments of flowers and fructification. Interesting, and occasionally very beautiful, as these are, they are singularly unsatisfactory in bringing us to conclusions concerning the climate and other conditions that prevailed in different parts of the world; but they are all we have to depend on, and we must endeavour to make out as many points as possible on which we may be satisfied.

The ferns and allied plants appear to have been infinitely more abundant in the formation of coal than any other tribe; and it would seem that these plants were at one time distributed over the northern hemisphere within wide ranges of latitude, to an extent, and with a degree of uniformity, to which there is now no parallel. In some respects this is indeed the case in the southern hemisphere, since in a few islands, especially Van Dieman's Land and New Zealand, the ferns are extremely plentiful, choking plants of larger growth, and admitting no under-growth of smaller species. The climate in such cases is temperate, equable, and damp, and the variety of species, both of ferns and flowering plants (especially the latter) extremely small. Many of the ferns found fossil were very closely allied to those now living; but while the total number of species met with in the British Islands is now only about fifty, the comparatively small areas worked for coal have already laid open for investigation more than three times that number. Judging from what we know of the present habits of similar plants, there is no reason to conclude that any other change of climate is thus indicated than would be produced by a different arrangement of the land and water.

"A climate warmer than ours now is * would probably be indicated by the presence of an increased number of flowering plants, which would doubtless have been fossilized with the ferns; whilst a lower temperature, equal to the mean of the seasons now prevailing, would assimilate our climate to that of such cooler climates as are characterized by a disproportionate amount of ferns. This, then, is an argument unfavourable to the theory of central heat having warmed the surface, or of the direction of the poles being so altered, as to have exposed Great Britain to a tropical climate."

Among the more important of the coal plants, forming a very marked feature in almost every coal field, appearing in all the beds near coal, and distributed from Spain to Scotland, and from Eastern Russia to the Alleghany mountains, are those singular trunks of trees known to fossil-collectors and naturalists under the name of *Sigillaria*. Upwards of sixty species have been described, but the definitions are very imperfect; and these fossils are but too well known to miners under various names, such as "bottoms" and "bell-moulds," which are stumps, often only a few feet high, but many yards in circumference at the expanded base, harder than the shales in which they occur, and when loosened from below, readily falling, unless propped, and often thus the cause of serious accidents. Besides these stems or stools, innumerable rootlets, often traceable from them, permeate in every direction most of the fine pure clays, underlying coal in

* Dr. Hooker. Memoirs of Geological Survey, vol. ii., p. 404.

some of the principal coal-fields. These rootlets, however, and the huge rounded masses with which they are connected, as well as larger roots, which also abound, are usually called *Stigmariæ* (see figure page 83); although it is now pretty certain that the so-called Stigmaria is really the root of Sigillaria.

It seems clear that the Sigillariæ were trees of brittle and open tissue, easily pressed flat, even by their own weight, after decay. They had cylindrical, straight, and sometimes lofty trunks, growing probably like palms, with great rapidity, and assuming from the first their full dimensions in diameter, but leaving broad deep scars by the falling off of leaves, which may possibly have been like those of the zamia, and not unlike some ferns in appearance. It is clear that a slender column, rarely two inches in diameter, passed obliquely through the trunk, and that the roots were of comparatively large size, and extended horizontally, radiating like the spokes of a wheel. Nothing is positively known of the foliage of this tree, although, as stated above, it is conjectured to have been fern or zamia-like.

Not far removed from the Sigillaria was the tree called *Lepidodendron* (see page 88), of which about forty species are described, and of whose trunk, branches, leaves, and cones a very satisfactory knowledge has been obtained, although the roots have not been identified. The name is given from the scaly appearance of the trunk left by decayed leaves. The tree diminished gradually in size towards the top, and branched at an acute angle; the number of branches being sometimes fifteen or twenty. These branches were covered with simple longish leaves, spirally arranged round the stem or twig. They are supposed to have resembled the club-mosses, some of which grow to rather considerable size in New Zealand, although in no case do they now approach the condition of a tree.

The only other very common and characteristic plant of the coal measures is that known as the *Calamite* (figure page 83), and generally described as representing, in a gigantic and exaggerated form, the common mare's-tail (*Equisetum*) of our marshes. In form, growth, and some conditions, there appears much similarity; but there are also some essential points of difference. Calamites abound in some beds near the coal; and, like stems of Sigillaria, they are generally flattened and horizontal, though they have also been found vertical and in groups.

The changes that have reduced vegetable matter, as seen in the fields and forests, to the state of coal, were manifestly very peculiar and local; for there is no reason to doubt that most parts of the earth have from the earliest time been clothed with vegetation, while true coal exists only in comparatively few districts, and is almost limited to a single one of those numerous periods described by geologists, each marked by the deposit of important mineral accumulations and distinct groups of fossils. The nature of the change is still obscure; for in many cases there is little evidence to show what was the vegetation of which the coal was really made up, although quite enough to satisfy us of the prevalent plants and trees capable of leaving behind trunks and leaves for examination.

Now it is clear that the mass of vegetable matter forming coal must either have grown where we find it, or must have been transported thither and accumulated by the action of water. If it grew on the spot, it might either have been in the way of moss forming peat bogs, or a continued accumulation of leaves and trees, there being, in either case, a possibility of the deposit being continued till it had attained a vast thickness, judging from the nearest parallel instances at the present day. If it were drifted, it may either have been so by rivers or marine currents.

The balance of evidence with regard to these two possible causes may certainly be regarded as in favour of an accumulation on low, flat, marshy land, constantly exposed to the intrusion of large quantities of mud or sand, brought by marine currents from some moderate distance, and constantly exposed also to slow depressions of the land, similar to those now taking place from time to time in Italy and the Mediterranean, on the west coast of South America, and in other volcanic countries.

The coal exists in beds varying in thickness from the tenth of an inch to a hundred feet or more.* These usually repose on fine clay, which is penetrated in every direction by the roots of plants, and shows no mark of the conveying current being strong enough to carry along trunks of trees. On the other hand, the beds above coal, if sandy, often exhibit proofs of such power in the broken state of the leaves and twigs, and the prostrate trunks lying in every direction. Not unfrequently the coal has been found very intimately connected with its underlying bed or floor, showing the relation that might be expected between a mass of miscellaneous vegetation and the ground on which it has grown. The main difficulty to be explained, in taking this view of the origin of coal, is the very frequent depression that must have occurred, and the immediate or rapid reproduction of land in a state to bear a similar growth of trees and plants to be again destroyed. It should be mentioned, indeed, that in thick seams there is rarely any continuous true coal of good quality without intermediate clayey or sandy bands, often black, and sometimes capable of being burnt, but altogether distinct from the coal itself. That many depressions do take place in volcanic districts, with alternations of repose, and even of elevation, is now well known from actual observation and measurement; and that a long period of time was required for the formation even of a single bed of coal of only moderate thickness is equally certain. Although, however, it is not improbable that the existence of a large proportion of the various beds of coal may be well explained, by supposing that the vegetable matter of which they are composed grew on the spot as trees, there is yet no impossibility that other modes may in some cases have prevailed, and that peat bogs and drift wood may also sometimes have supplied the requisite carbon.

The change that has taken place in producing coal from leaves, wood, stalks, or moss, is very considerable, and seems to have required either the lapse of a long period of time, or some circumstances productive of chemical action of a peculiar kind. The component parts of all vegetables are chiefly carbon, oxygen, and hydrogen; but a considerable part of the two latter elements are in the state of water, and a certain per centage of earthy matter and alkalies is also present. The water is sometimes actually ninety per cent of the whole plant, but generally in wood it forms from eighteen to fifty per cent. After a time, by pressure, and exclusion from the atmosphere, this water is to a great extent got rid of, and the carbon, if unable to combine with oxygen in the natural progress of decay, is preserved for an indefinite period, together with the earthy and alkaline ingredients. As time advances, further changes take place;—the external form becomes altogether lost, and even the texture is confused; but in this state again, wood can remain for a very long time without further alteration, and if then exposed to the air, it forms the imperfect fuel described as lignite. When, however, either by the influence of time or chemical action, a further change takes place, the proportions of the gases, and also of the mineral ingredients, are found to alter essentially; so that

* In England the beds no where exceed forty feet; but beds of lignite exist in various parts of Eastern Germany, and in Styria, whose thickness exceeds a hundred feet; and true coal is found in the department of Aveyron, Central France, in beds, one of which alone is upwards of fifty yards.

while in pure woody fibre there is about fifty-two and a-half per cent. of carbon, forty-two of oxygen, and five and a quarter of hydrogen, the proportion of ashes being less than one per cent., peat is found to contain fifty-six to seventy per cent. of carbon, twenty to twenty-five of oxygen, and ten to twenty per cent. of ash, while lignite with about the same proportion of carbon has much less ash, and thirty to thirty-six per cent. oxygen; lastly coal, when of good quality, has from eighty to ninety per cent. carbon, rarely ten per cent. of oxygen, and less than five per cent. of ash. In all these cases, the proportion of hydrogen remains; but in wood, peat, and lignite, it is combined with part of the oxygen in the form of water, and in coal, instead of the oxygen, a part of the carbon is combined with the hydrogen, forming carburetted hydrogen gas. This composition, with certain differences in compactness and uniformity of texture, is among the characteristic peculiarities of coal; and the more perfectly these conditions are fulfilled in any mineral fuel, the more the material becomes available as real coal. It is not unlikely that the gas thus formed occupies the place of water in the cells of the plant when in its new and mineral condition. At any rate, it is certain that on the removal of part of a bed of coal, the gas issues very freely from these pores in large quantity, and is occasionally so abundant as to be the source of extreme danger.

Thus, then, the nature and history of coal have been traced, and we see this substance reduced to its true position as a mass of vegetable matter originally bedded with clay and sand, and forming a component part of the mineral substances forming the earth's crust. We will next consider how far this position is available, and under what circumstances a substance so useful and so abundant can be best obtained.

Mineralisation of Coal.—Something of the position of coal has been already alluded to in a former paragraph, in speaking of its origin; and the usual accumulations of sand and clay in its vicinity have also been referred to, but we must now consider this point a little more closely. Beds of coal, like beds of clay, are rarely horizontal or parallel to the earth's surface for long distances; and, at however small an angle, they almost always cut the earth's surface in a line, which in uncultivated districts may often be seen, either in natural cliffs, in the beds or banks of streams, or wherever the first operations of road-making, however rough, cut through the coating of soil that interferes with our observation of the interior. Seen in this way, and at a slant section, the thickness of the beds often appears greater than it really is; while, as the coal is generally dirty and injured by exposure, the seams are by no means so easily recognised as might be imagined. The appearance of the coal, as of other rocks at the surface, is technically called the *out crop*, or more briefly, the crop; and from it alone the true thickness and value of the coal cannot be ascertained. For such purpose, trenches or shallow pits must be sunk, and the angle of inclination of the bed to the horizon be ascertained. The general limits of such lines of crop require to be marked on a good map, together with the position of other beds determined in the same district. When this is done, a general idea is obtained of the extent and value of the coal-bearing area, and some notion also as to the depth at which the coal may be worked, presuming that no irregularities exist underground. As, however, many such do exist, under the name of faults, slips, and troubles, it is always expedient to learn the extent to which they affect the position of the coal.

The general arrangement of rocks at the earth's surface, both in respect of their original regularity and subsequent partial displacement, will be understood by the reader of the preceding pages, who has attended to the chapter on Descriptive Geology. The action of the weather, and a thousand other natural and every-day causes, tend to

wear away exposed portions of the earth, and remove them to a distance. Every shower of summer, every frost of winter, every stream running over the ground, every wave beating against a cliff, or rolling shingle on the sea-beach, helps to bring about this result; and even the plants and trees growing on the soil, and the animals everywhere present both on land and in water, all do their share of this important work. The process of wearing away, and re-depositing that which has been removed, is thus as continuous and incessant as the lapse of time itself; and accumulations are now being made, though generally out of sight, which, in course of time, would appear as beds or strata, often of no slight dimensions, but for the most part quite horizontal.

There is probably no such thing in this world as an unchanging and uniform condition of things, even in those solid and apparently unalterable masses of rock buried beneath hundreds or thousands of feet of other minerals, and far away from observation. Certainly, in the accumulations made at the bottom of water, a transition state is that which immediately commences and prevails for an indefinite period, since the mud of a few centuries ago, which once contained an admixture of all kinds of animal, vegetable, and mineral matters, has now become half consolidated, its impurities collecting together or given off in gas. Afterwards, and while continuing to harden, it contracts and becomes cracked, undergoing at the same time a certain amount of re-arrangement of the atoms—the mud becoming either clay or limestone, according as it is argillaceous or calcareous, and assuming gradually that semi-crystalline structure so frequently observable, and causing the mass to separate readily into regular blocks and thin films. In the course of time so great a change has taken place, that were it not for the incontestible evidence of mechanical arrangement and fossil contents, it might often be doubted whether the regular beds seen in section in a sea cliff were really once mere muddy accumulations, and whether the band of shells, bones, or coal had its origin, as we know it had, in similar heaps of organic matter.

Thus it arises that a coal bed, seam, or vein (for it is called by all these names), is not so simple a thing as might at first be imagined. It is one of a number of phenomena which must be considered together, and with reference both to events going on now, and to others formerly taking place over large areas. It is not quite what it seems, for it has a history of its own, involving a long succession of events, the last of which was the elevation of the bed into its present position. We have already seen that coal is not now a mere mass of vegetation, though formerly existing in this condition. It is so far changed as to have become a mineral, alternating in beds with other minerals; altered by them, and having helped to alter them; broken up, re-united, lifted irregularly, partially worn, and occasionally, perhaps, drifted in mass. One coal seam also rarely exists alone. Whatever the reason may be—and it is undoubtedly very obscure—the causes that have produced a deposit of vegetation have generally acted so far at intervals, that it is more usual to find a number of moderately thin beds than one or two thick ones. But however this may be, the essential change has been superinduced; the vegetation no longer exhibits its cellular structure and original spiral vessels except at rare intervals; it no longer contains water, but instead of water it possesses the elementary gases, oxygen and hydrogen, of which the water was composed, both mixed with the carbon, the essential base, and forming the carbonic acid gas and carburetted hydrogen, which, exuding afterwards when the coal is broken, are the fertile source of the great dangers to which coal mining is more especially exposed.

The main changes to be considered are (1) the atomic alterations which make the essential difference between ordinary vegetable matter and mineral coal; and (2) the

mechanical alterations of position which render it possible to work—from the surface of the earth in hill sides, or at depths rarely much below the sea level—a vast series of deposits originally formed at or below the sea. It will also be fitly considered in this place how far geological age is important in reference to the probable existence of true coal in a district.

Speaking in a general way, and without introducing technicalities unsuited to the occasion, we have seen that coal differs from wood, peat, lignite, and other vegetable fuels, in having parted with almost all the essential ingredients of vegetation except carbon; while, on the other hand, it differs from various mineral substances, of which carbon is the essential ingredient, by still retaining at intervals indications of the actual structure of organic existence, as developed in the vegetable kingdom. These are, it is true, in a state utterly invisible to the unassisted eye, but they readily yield the secret of the origin of the substance to the microscopic observer. At the same time it is right to remind the reader that the steps are very gradual between organic matter loaded with mud and other similar impurities, and clay loaded with organic matter derived from vegetation, and communicating the peculiar and essential features of a combustible substance. So difficult is it to draw this line, and so little had scientific men thought it necessary, or found it possible, to create an actual definition in reference to this point, that within a short time a very important question arose in the Scotch courts of law as to whether a lease, granting the right to mine coal, should be understood to cover a certain mineral substance highly inflammable, and valuable for gas, but not really available as fuel. Owing partly to the fact that the lessor in the particular case had himself regarded this bed of bituminous shale on which the question arose as a real coal, the question was decided in favour of the lessee. But about the same time a similar question, in respect to the same material, as to whether it should be admitted on paying duty as a coal, or be passed free as a shale in the German customs' union, was settled the other way, the mineral being admitted as a shale eminently useful for certain purposes, but not a true mineral fuel. Certainly if coal is to be defined as a mineral fuel, and bituminous shales are distinct, the fact of a substance being valueless as a fuel after being deprived of its gas, is of some importance.

The essential peculiarities of coal as a mineral vary, however, very greatly; and this not merely in hardness, colour, texture, weight, fracture and other mineralogical characteristics, but also in actual composition, both positively as regards the total quantity of carbon it contains, and relatively as to whether this is associated on the one hand with considerable volumes of gas capable of entering into combination with carbon; and on the other, whether the proportion of earthy impurities is so large that the heating powers are dissipated and lost before they can be applied to get up steam in a boiler. All true coal is nearly free from water; but the oxygen and hydrogen, originally contained as aqueous fluid, are often large in quantity, and interfere with the efficient use of a coal as fuel.

Bituminous Coal.—There are various kinds of coal obtained from mines worked in the true coal fields, which may be grouped into *bituminous coal*, *steam coal*, and *anthracite*. Of the first, the *cannel* is a remarkable variety, the coarser kinds of it being called in Scotland "*parrot*," and sometimes *splint coal*.* It contains from forty to

* Splint coal is a name sometimes given to these less bituminous varieties of Scotch cannel; but it is also given elsewhere to hard and highly bituminous coals which burn with flame, but have little resemblance to cannel.

nearly sixty per cent. of volatile matter, and the proportion of carbon varies within the same limits. It burns readily, taking fire like a candle, and giving a bright light, and much smoke. The ash varies from about four to ten per cent.*

This coal yields, on destructive distillation, a very large quantity of gas, and is profitably used for that purpose. The gas is not only large in quantity, but remarkably pure, and of excellent quality for purposes of illumination. There is a large quantity of this kind of coal in the Scotch coal fields, and it has also been found in the Newcastle district, in the Wigan portion of the Lancashire coal-field, and in the Yorkshire and Derbyshire coal fields. America yields cannel coal in Virginia, Kentucky, Indiana, Illinois, and Missouri. Cannel coal passes into jet, and may, like jet, be worked into various ornaments; but it is brittle, and not very hard. The seams are generally rather thin, although there are several important exceptions, in which the quantity is very considerable. The coal of Belgium, from one basin (that of Mous), seems to be of this kind.

Another and far more abundant kind of bituminous coal is that obtained in Northumberland and Durham, and commonly used in London, and everywhere on the east and south coasts of England. This kind is also highly bituminous, burns with much flame, and takes fire readily; but it swells and alters its form while burning, often assuming a striking and very peculiar appearance. This caking coal, as it is called, yields on an average of several analyses, about 57 per cent. of carbon, about 37·6 volatile matter, and 5 per cent. ash. Its specific gravity is 1·257, but sometimes higher. It leaves a red ash in an open fire, but requires to be deprived of its volatile matter before being exposed to a strong blast, owing to its tendency to cement together in a solid mass, and prevent a free draught through the grate or furnace in which it is employed. Not only the coals of the Newcastle coal field in England, but most of those of France and Belgium generally, of Bohemia, and Silesia, in Europe, and of the valleys of the Ohio and its tributaries, in North America, are of the caking bituminous kind.

The coals of Staffordshire, Yorkshire and Derbyshire, Lancashire, North Wales, and many other districts, contain nearly or quite as much bituminous and volatile matter as those of Newcastle, but do not cake and swell in the fire, and may, therefore, be employed directly where strong heat is required without previous coking. The coke obtained from these coals is little altered in appearance. The coal burns freely, with flame and much heat, but is generally considered somewhat inferior for household purposes to that of Newcastle. It yields 50 to 60 per cent. carbon, 35 to 45 volatile matter, and a small quantity, often less than 5 per cent., of ash. The ash is often white. Most of the coals from the inland counties readily show white lines on the edges of the beds, owing to the pressure of argillaceous earth, which effloresces. In this respect they are less adapted for general use than the Newcastle coal, but many of them are of excellent quality.

Steam Coal.—Next in order to the coals of the midland counties generally, are those of some parts of North Wales, and many districts in South Wales, which contain a larger per centage of carbon, very little volatile matter and bitumen, and often

* Specimens of the so-called "*Boghead coal*," obtained from Jorbane hill, yielded on analysis as much as 73 per cent. volatile matter, and upwards of 20 per cent. of earthy ash. Other specimens yielded from 32 to 38 per cent. of earthy ash. In these cases from 27 to 43 per cent. of residuum was obtained on distilling off the gas, but of this from 75 to nearly 90 per cent. was earthy and incombustible, so that the material did not yield an available coke that could be used as fuel.

but little ash; which burn, however, freely and without smoke, and are well adapted for steam purposes and the manufacture of iron, or where a strong blast and great heat are required. Such coals exist not only in England, but in France, Saxony, and Belgium to some extent. They are apt to be tender or powdery, dirty-looking, and of comparatively loose texture, but they often stand exposure to the weather without alteration or injury. They are called steam coals, and the inferior kinds are known as culm. They contain of carbon 81 to 85 per cent., of volatile matter 11 to 15, and of ash 3 per cent. or thereabouts.

Anthracite.—The last kind of coal is called "anthracite," and it consists almost exclusively of carbon. This coal is also called non-bituminous, as the steam coal is semi-bituminous. The anthracites contain from 80 to upwards of 95 per cent. carbon, with a little ash, and sometimes a certain small per centage of volatile matter. They are heavier than common coal, take fire with difficulty, but give an intense heat when in full combustion with a strong draught. Anthracites occur abundantly in the western part of South Wales, in the south of Ireland, in France, Saxony, Russia, and in Pennsylvania and in North America, and the use of them is greatly on the increase. Amongst other uses, this kind of coal is employed in hop and malt drying, and also in lime burning, with great advantage, but its chief use is in the manufacture of iron. The appearance is often bright, with a shining irregular fracture; the coal is often hard, but some varieties are tender and readily fractured. The ash of the anthracite coal is generally white. As a general rule, the anthracites are deficient in hydrogen, but contain a certain proportion of oxygen gas.

Relative Value of Coals.—The following table represents the weight of water evaporated by one pound each of several principal varieties of coal, and is, therefore—other things being the same—a good index of the relative value of these fuels:—

		lbs.	oz.
Common Scotch bituminous coal		5	14
Hastings' Hartley main, Newcastle		6	14½
Carr's West Hartley, Newcastle		7	5
Middling Welsh anthracite		7	15¼
Merthyr bituminous coal, South Wales		8	0
Llangenech steam coal,	Do.	8	14½
Cameron's steam coal,	Do.	9	7¾
Pure Welsh anthracite,	Do.	10	8½

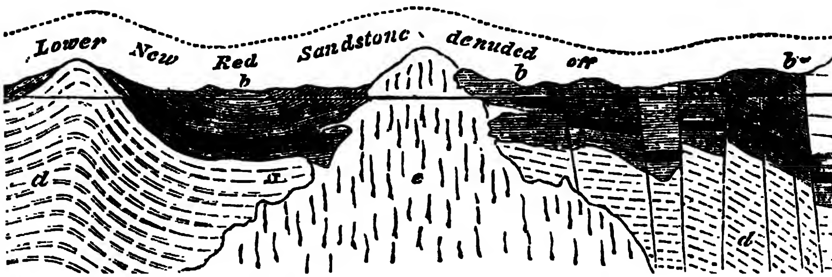
Age of Coal.—The geological age of coal is certainly not a matter of great importance, except in such districts as have been long known, and in which experience has shown that there is only one carboniferous series. Thus in England, France, Belgium, and generally in western Europe, the middle palæozoic period is the only one that contains thick and valuable beds of mineral fuel. Thinner and less valuable beds occur in the oolites, and lignites are found in rocks of much more modern date. Many English coal engineers, and even geologists, have hence come to the conclusion that coal did not exist, or was valueless, except when thus placed. Such a conclusion was partly borne out by discoveries in North America, where the chief deposits are of the same age as with us. There is, however, a great exception in the Richmond coal field, Virginia, which contains a fuel quite equal to many of those in common use, and is of the oolitic period. In India the exact age of the coal is not yet clearly determined; but everything points to the conclusion that, compared with the carboni-

ferous period, it is extremely modern, perhaps tertiary. In Australia, the age of the coal is also still doubtful. In a word, mere geological age is no guide in a new country,—the quality of the mineral, and the nature of the associated rocks, being the points that require chief investigation. Coal fossils of every kind are at present too little brought into relation with existing forms of vegetation to allow of their being referred to as evidence, except when placed in the hands of accomplished botanists, who have made extinct species their special study.

Position of Coal.—These remarks as to its condition are necessary to enable the student to understand fully the peculiarities of position in reference to coal. The beds of this material, as they exist now, include a singular variety of appearance, magnitude and condition, being sometimes perfectly regular over wide districts in nearly horizontal strata, and, as already experienced, of various thickness. Sometimes several hundred seams will be found, all parts of the same great series, and separated by thousands of feet of sandstone and shale; while occasionally there are only a few thick or thin beds, associated with masses of boulders, and barely covered up with thin deposits of little importance and of doubtful age. In one place we find the uniformity of certain seams so great, that in sinkings made through the strata at distant points the order can be recognised, and the particular part of a known field at once determined; but on the other hand it may happen (though not often in England) that in the same mine the thickness of a bed of coal is so variable, and the coal itself so irregular, that it would be impossible to imagine any relation between two not very distant points in the seam, if the workings were not continuous, and the mineral from one point actually continuous to another. A seam of coal sometimes terminates gradually, by thinning out to a mere line, and sometimes abruptly by a sudden break; while occasionally it becomes split asunder, and the upper and lower parts thin away, and are almost lost. The former case, that of gradually thinning out, shows a lens-shaped condition of the coal; while the latter, sometimes called a *horse*, shows the intrusion of a mass of clay or sandstone of the same shape between two parts of a coal seam. There is also sometimes an abrupt termination of the bed, either marking some local disturbance by which the coal has been removed to a distance above or below, or the result of an ancient denudation, by means of which the coal was formerly partly worn away by exposure, either being pared off by the direct action of the waves, or undermined and removed when soft underlying clays have been acted on at the foot of a cliff. Besides these cases, however, the coal is sometimes suddenly curved up and disappears for a time, as if an obstruction had existed at the time of deposit, and the vegetable mass had collected round it.

Faults.—With these remarks as to those occasional modifications of a coal-seam which naturally produce an appearance of irregularity, we may pass to the consideration of mechanical disturbances such as have produced the basin-shape characteristic of some coal fields, or, in a similar way, have brought over and over again to the surface many deposits whose dip would soon carry them out of range, and occasionally have so broken and destroyed particular districts as to deprive a locality of that value which would otherwise have belonged to it. The seams of coal are generally separated from one another by beds of sandstone, clay, and shale, known by various local names, and occasionally by bands of ironstone and even limestone, which have naturally been differently affected by subsequent mechanical disturbances. During the process of drying, all have contracted, but each in its own way; and thus the simplest condition is that of a number of cracks or crevices formed, which do not freely com-

municate with one another, but still have so far affected the general mass as to predispose them to fracture when upheaving forces acted. An illustration (see Cut) will be useful in showing the result of such upheaving force, which, however, is



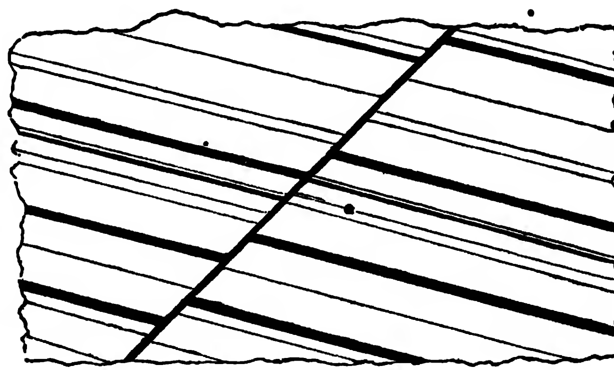
SECTION OF COAL FIELD AFTER DISTURBANCE.

rarely carried to the extent there indicated. In the cut, *b* represents the coal measures; *d*, underlying and older stratified rock; and *e*, an intrusive rock, such as basalt or porphyry. The latter, in being elevated, has lifted the stratified masses, and broken them. Some parts are greatly tilted in one direction; others also tilted, but in the opposite direction; while others between them are merely lifted more or less, without their original horizontal position being greatly affected. Water often finds a free passage through these crevices, while sometimes they are filled with clay, preventing the passage of water from one side to the other. The beds are often discontinuous on the two sides of a crevice; and the disturbance is then termed a *fault*, *trouble*, or *slip*.

It is often imagined by English colliers, especially those from the northern coal fields, that the existence of faults is an inevitable consequence of the very existence of true carboniferous rocks; and we find them alluded to by some writers as providential contrivances for the repetition of coal beds, so as to make them more available to man. A more extended knowledge of the subject shows that some of the largest and most valuable coal lands have either no faults at all, or so few that they neither interfere with the workings nor repeat particular seams of coal, which indeed are quite as often thrown out of reach as brought back by such results of disturbing force. The inclined position of the seams is another matter by no means universal, and the depth of the better kinds of coal, considerable in England in most cases, is much less in other countries; while in the great coal fields of America some of them are altogether above the water level, so far as effective workings are concerned.

Faults, however, are realities in English coal-mining, and require grave consideration. Taking the simple case represented in the annexed cut, some of the laws of faults, and their consequences, will be easily comprehended. In this cut, the thick black lines inclining to the right represent beds of coal, and the line more highly inclined and to the left the fault. The beds on the right side of the crevice or fault have in this case been lifted, and the fault is hence said to be *upcast*, or *upthrown* in that direction. This is true probably in the abstract, but when in working the seam in the usual way on its rise this fault is met with, the beds would appear to be thrown down to the left instead of being lifted to the right, and it would be spoken of as *downcast*, or a *downthrow* in that direction. In reality, as elevations of strata are far more likely to

occur than depressions in connection with these disturbances, the upcast is generally the correct description; but, practically, faults are spoken of as they are found, so that the same slip would be upcast in one mine and downcast in another if reached from opposite points. The important point to observe is the direction of the fault; for if that inclines, as in the case before us, to the left, the beds dipping to the right, it will follow that the angles made by any one of the beds in its two positions (before and after fracture) with the fault will be two obtuse angles, and thus a rule is obtained for following the seam. The practical rule is, that if the fault makes an angle less than a right angle with the bed of coal, the coal must be looked for at a lower level on the other side, being downcast in that direction; if, on the contrary, the angle is greater than a right angle, the coal will be at a higher level or upcast. It must be observed, that the distance to which the coal is heaved is not at all indicated by the nature or direction of the fault.



FAULT IN A COAL FIELD.

The crevices separating broken beds are sometimes filled with material drifted in from above, and sometimes with spar, soft clay, water, or even gases and powdered coal. Crystallized metalliferous minerals, such as galena, are also found. Many faults occur in which there is no perceptible interval between the walls.

Dykes.—Coal fields are intersected in various places by rocks apparently of igneous character, and called whinstone, greenstone, and basalt. In such cases there is often much evidence of chemical action, which has been attributed to heat. Whether these dykes were really in all cases intrusions of lava may perhaps admit of doubt; but the appearances are peculiar and striking, and worthy of special notice. For this purpose, a short notice of a remarkable whinstone dyke in the county of Durham will be interesting and instructive.

The dyke in question is of solid greenstone, ten to twenty yards in thickness, nearly vertical, and of unascertained depth. It is traceable to a distance of seventy miles, running in a south-east direction. The effect on the coal is thus described by Mr. Witham, in the Transactions of the Newcastle Natural History Society:—"Within fifty yards of the dyke the coal begins to change. It first loses the calcareous spar, which occurs in the joints and faces, and also loses its quality for burning. As it comes nearer it assumes the appearance of half-burnt cinder; and approaching still nearer the volcanic mass, it grows less and less in thickness, becoming a pretty hard cinder, and only two-and-a-half feet thick; eight yards further, it is converted into real cinder, and more immediately in contact with the basalt. It becomes, by degrees, a black substance called swart, resembling soot caked together—the seam of coal being reduced to nine inches in depth. There is a large portion of pyrites lodged in the roof

of that part of the seam which has been reduced to cinder. On each side of the dyke, between it and the regular strata, there is a thin gut or core of clay, about six inches thick, which turns the rain-water on the rise side, and forces it to the surface, forming numerous springs as it traverses the country. The coal deteriorated by the greenstone dyke, is twenty-five yards of bad short coal, half reduced to cinder; sixteen yards of cinder; and ten of sooty substance."

If a similar effect has been produced on the rise side, of which there is little doubt, it will make altogether upwards of one hundred yards of coal rendered unfit for colliery purposes. The dyke itself at this point is eighteen yards in thickness: water-worn stones have occasionally been found embedded in the solid coal in the main seam.*

Other dykes of smaller magnitude are common in particular districts, but rarely range beyond them. They are occasionally connected with faults of enormous magnitude, but sometimes are independent of disturbances. The extent to which beds are faulted, or removed asunder in vertical distance after being broken, may be said to range between a-tenth of an inch and a thousand fathoms; but in coal fields a few fathoms is as much as is usually met with.† They are often repeated several times within a short distance, producing a condition technically called *broken ground*, greatly interfering with the profitable working of the seams.

The width of faults in ordinary cases is small; but even those not filled up with altered rock are sometimes separated many fathoms. In such cases considerable practical difficulty is experienced in conducting workings and re-discovering the lost seam of coal.

Coal Sections.—Coal is so differently circumstanced in different coal fields, with reference to the associated rocks, that a few words as to coal sections may be useful. These are extremely valuable for comparison in the same districts, but equally liable to mislead when supposed to be generally applicable. There is really no necessary resemblance whatever in the beds associated with coal, in different districts; nor can any deduction be drawn, except in the most general way, from the presence of those shales and grits which, in particular cases, in England are regarded as almost infallible guides. No doubt, a certain amount of mud and sand is usually, though not always, connected with coal seams; and thin beds of clay, containing the rootlets of trees, are often found immediately underlying coal, and when present may be regarded as showing a proba-

* Mr. Francis Forster, in 1830, published an investigation of the nature of the several specimens of basalt, coal, &c., from this dyke, of which the following are extracts:—

"The basalt is light gray, fine-grained, and compact, interspersed with crystals of felspar—specific gravity, 2·672; losing eight per cent. in a strong air furnace heat, and becoming fused into a brown glass. The coke, or carbonized coal mixed up with the basalt, is extremely hard, fracture uneven, gray, mixed with irregular streaks of carbonate of lime and sulphuret of iron—specific gravity, 1·957; that of the coal which it represents being 1·27. The coke, when reduced to powder and calcined in a strong red heat, leaves twenty-three per cent. of heavy incombustible powder of a reddish colour.

"It is remarkable that the coal, although reposing immediately upon the ten-feet beds of basalt, should retain the above properties.

"The ten-feet stratum of carbonized coal—specific gravity 1·660—when calcined in a strong red heat, are thirty-five and a half per cent. of a dirty white powder, chiefly silicious, containing a minute proportion of iron."

† The principal fault in the Newcastle coal fields is from 90 to 130 fathoms perpendicular, and is regarded as a *down throw*. It brings into workable position, a second time, several important seams, cropping out near Newcastle. Two other main faults traverse this district; one of forty fathoms, and another of twenty-five. There is no basalt or altered rock connected with these remarkable faults.

bility of the existence of coal. These are usual, but sometimes the coal is merely embedded with conglomerates of the coarsest kind and most irregular composition, and in these cases it may repose on granite or gneiss and not present any covering of newer rocks. Thus, the *red measures* ceasing to guide the miner above, and the limestone or millstone grit below, there remain no sufficient means of identification.

Ironstone and Pyrites.—Many seams of coal, and indeed most other deposits, either contain, or are near, some form of iron. In most cases the oxide of iron colours the sandstones and clays; occasionally it fills veins immediately adjacent, and sometimes it collects into bands of impure iron ore. Elsewhere, the same metal, combined with sulphur (iron pyrites), appears in thin bands, alternating with or actually embedded in coal; and occasionally bands of ironstone (impure argillaceous carbonates) alternate with the coal, and may be extracted at the same time. The latter are extremely valuable, and in large districts in England and Scotland afford the principal ore of the metal. They may be regarded as segregated nodules in clay. The former condition, that of iron oxide in veins or bands, is comparatively rare in this country; but the ore is richer and more valuable. The iron pyrites, wherever it occurs in coal measures, is at the best valueless, and often extremely mischievous; as, by the decomposition of the mineral on exposure to moisture and oxidation, a considerable amount of heat is liberated; and spontaneous combustion has often taken place, either in the heaps at the mouth of the pits, or in vessels or stores, when a considerable quantity of damp coal is thrown together. There is no more important inquiry, in reference to coal measures, than the condition of the iron, and the increased or diminished value thence arising.

The iron stones of the coal measures usually consist of irregular bands of detached nodules, a few inches in thickness. Some of these average three to four hundred weight to the square yard, and contain from 25 to 30 per cent. of iron. The richer bands of the same kind from Staffordshire, Worcestershire, and Shropshire, are heavier and more regular, and yield 40 per cent. of metal; some of them being two feet thick. The *black band* of Scotland varies from fifteen or twenty inches to five feet in thickness, and resembles the black shales common in the coal measures. It is widely spread, easily calcined in heaps with waste coal, and when roasted yields as much as 60 per cent. of iron in a calx easily melted in the furnace. The other ironstones not belonging properly to the coal measures do not here come under consideration.

Open Works.—Coal seams, alternating with other rocks of whatever kind, are easily recognised at the surface, and their position underground must be estimated by calculation. If they appear nearly horizontal, and are above the level of the water in the adjacent country, they may be entered at once, or the coal can be removed by a process analogous to that of quarrying. This is the simplest method of coal mining; and, though rare and exceptional in the British Islands, it can be adapted with great advantage in North America and in some of the most valuable coal fields of France. The discovery and working of the coal under these circumstances is very inexpensive. More usually, however, the beds of coal, though coming to the surface, dip into the earth, and at a moderate distance from the outcrop can only be reached by sinking pits often to great depth, and then performing many costly mining operations dependent on the nature and thickness of the coal, on the amount of its dip, on the extent to which it is faulted, and on the peculiarities of structure and condition of the sandstones, clays, limestones, or conglomerates alternating with the coal seams. There are thus several modes of coal mining, each pursued in some particular district, and each containing

more or less of general principle, which the student in this department would do well to learn.

The original discovery of a coal seam is not difficult, and is generally made on some natural exposure on a cliff, in a valley, by a stream, or wherever—in a word—the surface coating of soil being absent, the underlying rock can be seen. At the surface the bed is often weathered and rotten, and little indicative of the importance of the mineral wealth present. The discovery once made, if the coal seam is horizontal, and above the level of the water, it can be entered at once, and a considerable quantity of coal extracted. This is the case on the banks of the Ohio and its tributaries, in the neighbourhood of Pittsburg, and elsewhere in the same field. Something of the same condition may be found in the thick seams now worked at Aubin and Decazeville, in the department of Aveyron, Central France. In the latter case, indeed, the vast thickness of the principal seam (one hundred and fifty feet), and the thin coating of soil and rock above it, has rendered it possible to commence open workings after removing the superincumbent rubbish. In the former, the works are carried on by means of tunnels burrowed into the side of a hill, commencing at some point where the coal has been laid bare half way up the steep banks of a river. The cost of working is, in either case, extremely small, and should hardly exceed a shilling or eighteen-pence per ton at the mouth of the tunnel. Such a tunnel or gallery is called, in mining language, a *level* or *adit;* and the coal being pierced by one such level, and cut into by others, driven through to right and left, a large quantity can be readily obtained with very little difficulty.

Deep Workings.—In the case of deep coals it is certain that no general rule of working can possibly be applied to all; and each individual seam, and group of seams, must be dealt with according to the thickness of the coal, its dip, or angle of inclination to the horizon, its hardness or tenderness, the quantity of gas exuding from it, the nature and extent of the faults, the nature of the roof and floor (or beds immediately overlying and underlying), the depth from the surface of the workings, and many other circumstances.

Still, notwithstanding these points, there are distinct methods, some one or other of which is more applicable than others in each particular case. The method of working highly inclined seams (edge coals), is different from that used when the coal is horizontal or nearly so; the method when the roof is bad and leaky, the coal near the surface, free from gas and thick, and the property of moderate extent, is also different from that required when the seam is of average thickness (not more than ten feet), with good roof, deep, and abounding with gas. A short description of the preliminary processes of boring and sinking, which are required whenever the coal lies deep, and of the principles involved in the different methods alluded to, will afford sufficient illustration of coal mining for the purposes of this treatise.

Boring is an operation not peculiar to coal mining, though largely used for that purpose as a preliminary to sinking, in doubtful cases. This process removes a small portion of the rock, and enables the material to be observed, and a correct opinion obtained as to the feeders or springs of water pierced. It is not expensive for moderate depths, but tedious and costly when carried down beyond fifty fathoms of ordinary ground. Several borings are desirable in an untried field, in order to obtain a fair opinion as to the direction and amount of the dip, the presence of faults, the thickness of the coal seams, the nature of the roofs, &c.; and also in an old and partly-worked district, when former workings are suspected to exist, but are not accurately known, and are supposed to be charged with gas or water.

Shaft Sinking.—When the position of a coal seam has been determined, or is known, and some idea of the property obtained by boring, it is necessary to sink a shaft to reach or *win* the mineral. When the distance to be sunk is inconsiderable, and the dip small, the position of the pit is of little importance, particularly where there is no amount of water to be apprehended, and nothing unusual in the rocks to be gone through. A pair of pits should then be put down at once, and the diameter of each need not exceed eight or nine feet diameter, unless, indeed, pumping is likely to be required for the removal of water. In this case the engine shaft must be somewhat larger. Where the coal is deep, the sinking expensive, and much water likely to be met, the expense of two pits has sometimes been regarded as too great, and one large shaft of fourteen or fifteen feet resorted to, a division being made in it by wooden partitions of great strength, technically called *brattices.* It is hardly considered good mining, at the present day, to sink a single shaft under such circumstances; nor is it altogether justifiable, as the danger, in case of accident from any cause, is far greater than when two are adopted.

The depth of existing shafts extends, in some few cases, to as much as three hundred fathoms. One hundred fathoms is, however, a depth below which it is not often required to go in order to reach coal in a known coal-field, where the works are not of an unusual character. In such case, great hardness of the rock, the presence of soft sands and unsound rotten clays, or a large body of water, are the chief causes of extraordinary expenses in the operation.

When a sinking has been carried on through the vegetable soil, and alluvial or diluvial covering, and has reached the actual rock (the stone strata, as they are sometimes called), water may be expected, and may come either from surface springs depending on the seam and the surrounding country, or from partial feeders which gradually decrease and ultimately die out, or permanent feeders connected with large areas of drainage, and remaining unaltered for years. These latter must, at any expense, be stopped back, and not only prevented from entering the shaft at the time, but from draining down into the mine when the shaft is ultimately completed. Every important feeder, or spring of whatever kind, must, however, be carefully kept back in a shaft intended to work a deep and important mine, and a large property.

Tubbing.—There are several kinds of stopping out water, or *tubbing,* as it is called, commonly used. *Stone tubbing,* which involves merely a water-tight stone wall, jointed and fastened at the back with cement, and answers for light pressures, but is not to be trusted in important works; *Plank tubbing,* often adopted in old mines, and capable of being made very strong; *Solid wood tubbing,* a great improvement on planks; and *Metal tubbing,* now commonly resorted to, and far the most efficacious. The wooden tubbing was usually completed with two and a-half or three inch deals, and would, when fresh, bear a pressure of one hundred pounds to the square inch. Exposure, however, frequently injured it. In all cases, the foundation of a permanent *tub* should rest on a water-tight stratum.

The present mode of tubbing with segments of cast iron, is both more rapid and more efficacious than any other. The size and thickness of the iron varies according to the expected pressure; but, generally, the length is from three to four feet, the height two feet, and the thickness about an inch, or even more in serious cases. The segments are fitted by overlap flanges at each end. During the time that the tubbing is being fitted, the shaft has to be kept dry by pumping. This is often a very serious difficulty, as may be supposed from the fact that many thousand gallons of water per minute may

have to be lifted the whole length of the shaft. The tubbing, when well constructed, is perfectly efficacious, and the shaft left completely dry for further sinking. In certain cases, however, the springs of water thus kept back are charged with mineral salts, and are extremely corrosive; and here the iron in time becomes altered, and even changed into a kind of impure plumbago, sufficiently soft to be cut with a knife. When thus weakened, the tubbing has occasionally given way, letting down the water and drowning the mine. Several springs are frequently met with in sinking to a deep recovery. Each of these has to be treated separately, and tubbed out independently.

Plans of Working.—We may now suppose the collier so far advanced as to have reached the seam of coal he is about to work, and it remains only to remove the mineral from its position in the bed, and bring it to the surface fit for use or sale. There are, however, several ways of proceeding, each of which has its advantages, and is adopted in some particular district; and we must consider the essential features belonging to those of most importance.

It may, indeed, be thought strange that any great difference should exist in the mechanical contrivances for removing a mineral which everywhere possesses the same general characteristics. But, in the first place, coal differs exceedingly in thickness, in the facility with which it is worked, in the abundance of inflammable gas given off, in the power of resisting pressure, and in many other points of importance. Besides this, the roof and floor vary extremely; the depth of the superincumbent mass is in some mines far more considerable than in others; and the style of working must even depend, in some measure, on the magnitude of the property, and the number of acres of coal to be extracted. Thus it is that a plan of working is really essential, and the object of the plan will be, to get as much as possible of the coal in a large state (called round coal) at as low a cost as can be contrived, and without running a risk of the remaining coal being crushed or injured by the subsequent falling in of the roof. Where possible, almost the whole of the coal should ultimately be obtained.

The methods of working adopted in England may be grouped into three, which, however, are often combined. These are—*first*, the pillar and stall, or bord and pillar, adopted in the Newcastle coal-field; *secondly*, the long wall, as adopted in Derbyshire, and some parts of Yorkshire; and, *thirdly*, that employed in South Staffordshire for working the thick coal. Of these, the former is by far the most completely developed, and admits of the most perfect ventilation, but it is not so economical as the second. The third is only a modification adopted when the coal is too thick to be got out by one level. The principles involved in each method are easily explained.

In working by the bord and pillar, the coal is at first got only from comparatively narrow galleries, parallel to each other, cut through the coal on its rise; and others, at intervals, intersecting them at right angles. Thus the whole of the seam of coal within the property worked is reduced to large rectangular pillars between these galleries, the pillars being left to support the roof. The shaft being supported by sufficient coal all round, and the roads also protected in a similar way, the mine is safely worked in this fashion; and afterwards, by cutting the pillars through and at last removing them, replacing the coal for a time by stout wooden props, which are also ultimately removed, a large per centage of the coal is got away, though in most part of the pillars it is too much crushed to yield round coal. There is thus a considerable loss, and the roof is left to fall after the coal is removed, thus producing a broken hollow, like an inverted funnel, technically called a *goaf*; or else allowing the surface to sink in what is known as a *creep*.

Of late years all large mines have been worked in panels, or divisions, shut off from one another by a sufficient thickness of coal to prevent an accident from extending beyond one panel, and allowing of better regulation of the ventilation. When the great magnitude and importance of ventilation in a coal-mine is taken into account, the value of this modification will be felt to be very great. We shall have occasion to recur to this subject.

By the long wall method the whole of the coal is got at one operation, either by working from the shaft towards the rise of the coal, and making safe roadways through the fallen roof by strong stone continuous pillars, or by driving first to the extremity and working the coal back towards the shaft, leaving the goaf, or rubbish, of fallen roof behind, and neglecting to keep roads through the goaf. Where the goaf is not dangerous from the presence of gas, and the roof will admit of it, this method is both economical and efficient, as the whole of the coal is at once removed on a long face, and is not subject to the partial crushing that takes place when pillars are left.

The thick coal is worked in south Staffordshire, and the neighbourhood, in a very irregular mode. Small pillars are left at irregular intervals, and sometimes these pillars are removed; but in all cases there are walls of coal left at moderate distances apart. The coal in this district is parted by thin bands of clay, but the whole is removed. In all these cases the general system of working, when the coal is reached, is in some respects the same; a deep groove being cut into the bed at its lower part, and the rest thrown down, either by wedging or blasting.

Noxious Gases.—There are causes of danger and expense in coal-mining which are, to a certain extent, independent of the ordinary mineral and geological condition of the measures, but which often require the application of great experience and engineering knowledge. Each of these also may be regarded as capable of affecting, in almost any degree, the value of coal property, and modifying the style of working. The faulted structure of carboniferous rocks, already alluded to, is one of these; and a knowledge of the systems of faults that exist in a coal-field is of extreme importance to the scientific viewer,* and should be the object of his careful and never ceasing study. Connected with this is the question of water, also vitally important, both as involving management in sinking, and in subsequent pumping from the bottom, where sometimes there are large feeders tapped. But the fact that many kinds of coal not only yield large quantities of light carburetted hydrogen gas on distillation, but exude such gas on simple exposure, especially when recently laid bare and remaining under pressure, is far more important, as involving the necessity of careful ventilation through all the workings, and, in spite of all care, becoming the fertile source of some of the most frightful accidents by which human life is destroyed.

The gas thus referred to is called by miners *fire-damp*, or simply *damp*, and is only met with in mining certain kinds of coal. It is especially abundant in the Newcastle coal-field; and this, combined with other causes of difficulty and danger, has rendered it necessary to bring to bear in that district the greatest amount of skill and caution. Elsewhere what is called *choke-damp* prevails, this being carbonic acid gas; and it is not unlikely that other gases are mixed from time to time with these. When it is remembered that a large number of men, and often many horses, are employed underground, and that frequently there are miles of underground passages and hundreds of miners without more than two or three shafts communicating with the upper air—and

* The engineer who is responsible for planning and superintending coal-mining operations, both above and underground, is technically called a *viewer*.

these only chimneys, many hundred feet long, and of small area—no one will be surprised that the air becomes vitiated, and that a small addition of foul gas renders it unfit for the support of life. Where, however, gas of whatever kind comes off with any degree of regularity, the mechanical means of ventilation commonly adopted, and which will be presently described, are sufficient. It is only when there are sudden, unexpected, and large jets of gas instantaneously poured forth, and when this gas, mixed with common air, becomes highly explosive, that the real danger arises.

Fire-damp.—It has been already said that gas, such as is commonly burnt to light our streets and houses, issues from a freshly-exposed surface of coal in the mine. This gas is much lighter than common air, and when first liberated remains in the hollows and irregularities on the roof adjacent. But it soon mixes with the air around; and when, either from faulty ventilation or excess of gas liberated, the quantity of gas amounts to or exceeds one part in fourteen of the atmospheric air, the mixed air thus produced becomes highly explosive. If it continues in this dangerous state, the air in a large part of the mine may become similarly explosive; and on contact with naked flame it suddenly takes fire—the result being the production of a large quantity of carbonic acid gas, and a little aqueous vapour, the whole absolutely and immediately fatal to existence. Thus a coal-mine accident from explosion is not only a fearful risk to all those within the limits of the scorching flame, but certain death to all who are exposed to the poisonous gas that remains. The issue of the gas in the mine, in the ordinary way, is recognised by a peculiar hissing, or low singing noise, distinctly heard when other noises are quieted, and even recognisable sometimes when several people are talking together. This noise varies in different mines, and seems to be affected by atmospheric conditions, increasing when the barometer falls, and diminishing when it rises. The quantity of the gas thus given off varies considerably,—some mines becoming dangerous if the ventilation is checked for a very few hours; while in others, where the singing is not less marked, many days would be required to produce this effect.

It is not quite clear whether the gas comes off in this case from the whole of the exposed surface, or only from the edges between two of the thin films of which each stratum is made up; nor is the exact nature of the gas evolved in all cases the same. But these are points that belong rather to the chemistry of the subject, and which need not here be discussed. The important matter of fact in the coal-mining question is this, that in certain mines a gas is given off, which, on mixture with atmospheric air, becomes explosive; and it may give an idea of the extent to which this ordinary issue may extend to mention that, in an instance on record (the first workings of a seam in the celebrated Wallsend pit, near Newcastle-on-Tyne), the coal actually gave off sufficient gas to have lighted the pit. In this case small holes might be drilled in any part of the solid coal; and on sticking a tin pipe in the aperture, and applying a light, a flame was produced,—so that the whole face of the working was, as it were, a gas-pipe; and when shots were fired for blasting the coal, the gas was generally fired at the same time without explosion.

Now whatever be the quantity of gas given off from the pores or edges of the coal, the ventilation of the mine ought, under all circumstances, to be more than sufficient to carry it off. If it is not, the danger is so imminent that it can scarcely be considered less than wilful exposure to destruction to proceed to work in the mine at all; for the slightest derangement of any part of the apparatus for ventilation is then almost certainly followed by an accident. But these extreme cases are rare; and there is generally no difficulty in contriving a ventilation which shall carry off the quantity

ordinarily liberated. The dangerous part of working a mine is often not considered to have commenced in this early stage of the works; and it is usual, in working the whole coal, to use only open candles, in spite of risk. It is an important fact, that, notwithstanding this opinion, numerous accidents on record have happened when the workings were in this state.

There are, however, other cases in which the gas is liberated not so continuously as in that just alluded to, and in a much more dangerous way; these unhappily can scarcely, if at all, be guarded against, and seem beyond the chance of improvement by any methods of ventilation.

It may be considered as a principle in coal mining that the ordinary ventilation should carry off the constant issue of gas without allowing it to accumulate and become dangerous; but from time to time it happens that at some crack in the coal seam, or some fault or slip, often quite insufficient to derange the general plan of working, there proceeds suddenly, without warning, and apparently without any cause, a puff of gas, which will continue sometimes for a longer and sometimes for a shorter time, and sometimes perpetually; everything about this being uncertain, and therefore not to be provided against. A remarkable instance of this kind, the result of which was an accident by which ten persons were killed, took place, a few years ago, at Killingworth, in a very extensive and long-worked pit, on the north bank of the Tyne. The particulars of this accident are interesting and instructive, as it occurred while working the whole coal, with open lights, in a mine under the management of Mr. Nicholas Wood, one of the most eminent viewers in the kingdom.

Killingworth Accident.—In this case, the immediate cause of the accident was traced to a small fault, which had been reached some time before, but which had suddenly (between the going off of one set of men, and the coming in of another) liberated a large quantity of gas, and filled a space of about two hundred cubic yards with highly explosive gas. The roof was hard, and the crack barely sufficient to allow the hand to be put in it. The explosion took place in consequence of the foolish advance of a boy, with a lighted candle, who preceded the man whose business it was to observe the state of the workings. All the party were killed, and stoppings or walls were blown down, consisting of two ten-inch brick walls, and a series of five alternations of one yard of rubble wall, and four feet of rubbish, to a total thickness of forty feet. The gas continued to issue rapidly, and for thirteen days after the accident might have been lighted and burnt. At that time, indeed, it was impossible to approach the scene of the explosion within several yards with a lighted lamp, as the atmosphere contained too small a proportion of oxygen to support flame.

It will be seen that the danger was here absolutely impossible to provide against, as increased ventilation would, if anything, have increased the evil, and no ventilation could have been so contrived as to carry off a sudden addition of so large a quantity of gas without forming an enormous quantity of explosive mixture. On the other hand, the immediate cause of the accident was carelessness of the grossest kind on the part of the man, whose chief duty it was to go first to see whether danger existed. Had he done this, he would have been able to discover the state of the workings, and might have prevented the accident by giving timely warning to the men bringing open lights.

Goaf.—Another cause of danger, which has not been provided against, but which, though undoubtedly very serious, does not appear to have been followed by many accidents, consists of the accumulation of gas in those broken roofs of the mine which are known locally under the name of *goaf*.

The goaf is the result of a peculiar mode of working the coal, by which the roof of sandstone or shale is allowed to fall by degrees. It should be stated, however, that there are three distinct methods of working, in which a goaf occurs—namely, the leaving a goaf entirely behind, leaving it partly behind, and leaving it in the middle of the works. The opinions of practical men in the north are still divided as to the relative value and relative danger of these methods; but the ventilation that would render the one safe would manifestly be useless for another; so that here, again, the elementary principles of coal mining, with a view to ventilation, require to be carefully adapted to the particular case.

The goaf being of the nature of a funnel, the light gas will drain into the upper portion of it; and in cases where there are not many faults, might sometimes be brought to the surface in shallow mines, either according to a method proposed by Mr. Ryan, and adopted in South Staffordshire, or by the upper strata being pierced or bored from the surface before being worked. The former method consists in running a gallery, or headway, as it is called, above the working headway to the highest place worked, and boring down from different points to meet the coal. The gas then escapes, rising naturally to the surface. It is probable that the adoption of this method might at least some times be tried in the north of England with advantage; but it is no doubt more likely to be successful in the mines of Wales and South Staffordshire.

Jarrow Accident.—An accident that occurred at Jarrow Colliery, about the same time as that at Killingworth, was also the result of a blower or feeder of gas suddenly given off; but in this case the exact spot was not known, as the gas had ceased to come away when the mine was in a condition to be examined. At the great explosion at Haswell, on the other hand, on the 28th of September, 1844, the accident occurred near the goaf; and as it illustrates another point of interest, it is worth while to give a brief account of the accident.

Haswell Accident.—The Haswell Royalty includes about a thousand acres of surface, and was at that time worked entirely from two shafts. In the seam in which the accident happened (the Hutton seam) the greater part of the mineral has been already obtained and the pillars left to support the roof have been partly taken away. The districts in which the coal is worked (the *panels*) are not very large, but unfortunately they have been allowed to run too much into one another. The accident occurred, it is supposed, at or near a particular spot where two of the divisions or panels approximate.

Now if in this case the separation between each panel had been complete, and there had also been a distinct passage from each panel to the pit-bottom, it is certain that all the persons in the other panels might have been perfectly safe. As it was, between forty and fifty persons were unfortunately left in the working most distant from the pit bottom, not one of whom escaped. More than half the whole number killed might probably have been saved if a free and safe communication had existed.

The practicability of adopting any method that should have for its object the complete separation of different workings of the mine, depends partly on expense and partly on the degree to which the main current of air can be so far subdivided as to ventilate many distinct districts. In both these respects the case is clear and satisfactory.

Ventilation.—Let us next consider how all these different points bear upon the main subject of the ventilation of coal-mines, as connected with the most economic and safe methods of working such mines. From the very nature of the case, we have a number of tall chimneys (usually considered necessary and sufficient to create a strong

draught of air) in the shafts already sunk to reach the coal; we only require, therefore, some means to set the air in motion; and of all means the furnace is the most ready and natural. In a coal-mine, accordingly, where there are two shafts, or where in the absence of a second shaft, the one is divided into two parts, a furnace is always placed at the bottom of one, and forms what is called the *up-cast*, conveying again to the surface the air which has been drawn down the other, or *downcast* shaft, after it has been forced to pass through all or part of the workings. The air brought into the mine through the downcast shaft is called the "*in-take*;" and when it has got past the chief working, and is on its way towards the upcast, it is then called the "*returns*."

The furnace offers a means of producing almost any amount of ordinary ventilation; and by means of contrivances easily applied, it is a safe resource, even when part of the air brought out of the mine is in an explosive state. This portion is generally conducted along a separate course, and made to enter the shaft twenty or thirty feet above the furnace. The draught is there sufficient to carry it up; or if not, a portion of fresh air, admitted from below, effectually and safely gets rids of it. A contrivance of this kind is common in all fiery mines, and is called the dumb furnace.

When a quantity of air is thus obtained in circulation, the next matter to be discussed is the best method of making use of it.

Coursing the Air.—There is one very obvious method, which was for a long time adopted—namely, to force the whole of the air to pass in succession through all the passages and galleries by preventing communication between them except in one direction. But it was found, after a time, that this simple method was both inefficient and unequal. In order to get any current at all in the ascending column, it was necessary to have a very large supply drawn along narrow passages for a distance amounting in some cases to sixty or seventy miles. The rate of progress was of course very slow, and the risk of danger enormously great; while if the air was foul anywhere, the whole of that gas was carried through the rest of the workings, and the ventilation, for all effective purposes, lamentably deficient. Pairs of galleries were sometimes ventilated together; and often a large extent of the broken, or district whence the coal had been partially extracted and the pillars left, was often altogether unventilated. It was found, however, at last that if a current of air was allowed to select between two districts, both of which communicated with the upcast, it did not take the shortest way and leave the other untraversed, but divided itself,—a certain part going off through one set of galleries, and a certain part also through the other set. When it was tried what the quantity of air thus passed in each case might be, it appeared that the sum of the two quantities was very much greater than what had passed through before In this way the important principle was established, that *the quantity of air brought down into a mine might be increased by increasing the number of distinct currents to the upcast shaft.* It remained to determine to what extent this method is available.

Splitting the Air.—Experiments are still wanting to settle, in a satisfactory manner, this extremely interesting and important question; but to obtain some idea of the immediate effect, an experiment was made by the author, accompanied by Mr. Nicholas Wood, in a new mine (Tyne main), at a time when it had been only recently opened, on the south bank of the Tyne. In this mine the air, as it reached the bottom of the downcast shaft, was split into three currents, the principal one going into the north district. On measuring this, by counting the number of seconds during which the smoke of gunpowder is conveyed for a certain distance, it was found that twenty thousand cubic feet per minute must have passed into the workings, moving at the rate

of four-and-a-half miles per hour. Having decided this, a communication direct to the furnace was opened, by means of which free way was allowed to the air to escape immediately to the surface; but the effect was only to reduce the supply into the workings from twenty thousand to sixteen thousand feet, although the total amount of twenty thousand were now passed over the furnace direct. The quantity of air brought down was thus increased by four-fifths of its former amount by this operation of splitting.

The result of the discovery of this power of splitting the current of air has been extremely important. Instead of the air travelling forty, fifty, or even seventy miles, as it did formerly, it is now rare to find an air-course of greater length than about four miles in a well-regulated colliery. There can be no doubt that the general health of the miners must be improved, as well as the danger of explosions lessened, by the introduction of the plan.

It should not be forgotten, that a due application of such a method requires some knowledge and experience. In order to obtain full benefit from it, the mines should be properly superintended; for although these methods are adopted and admirably contrived so as to be most effectual in the larger mines, yet where there is no constant superintendence of an intelligent viewer, it is scarcely to be expected that any great care should be taken about the matter.

Doors and Stoppings.—The principle of splitting the air once admitted and applied, the actual ventilation of a mine requires that there should be provided a certain set of doors and stoppings, some permanent, some moveable, some only partial; all of which require to be well planned at first, adapted to the general method of ventilation, and constantly superintended by efficient overseers. Much of the value of the ventilation depends on minute attention to details, which it would be tedious to describe; but perhaps it may be worth while to mention the nature of the different kinds of doors, and their uses.

Stoppings have been already alluded to. They are of the strongest possible construction, sometimes twenty yards thick, and constructed of brick and rubble wall and rubbish. Notwithstanding their strength, they are often blown down in case of an explosion. Small openings, about twenty inches square, with what are called *main doors*, sometimes communicate through a stopping.

The *main doors* are far less solid than stoppings; but are still very strong, made of the best materials, and closing accurately. These are always placed in pairs, with a space between them, so that one may be closed while the waggon is going along, and before the other is opened. In the most important places there are three such doors.

Shell doors are less permanent than the former kind, and are used in places where the work is proceeding. They communicate through the brattices, or wooden partition walls which conduct the column of air.

Sham-doors only check and do not prevent the passage of air. The air which escapes through the doors is called the *scale*, and is sometimes used in partial ventilation.

Boys and old men are generally intrusted with the opening and shutting of doors; and much of the safety of the mine depends on this being properly attended to.

In the management of the ventilation and the distribution of the return currents, which all gradually unite into two, it is often necessary that one current should pass over another. This is effected by a strong brick arch called a *crossing*.

Candles and Safety Lamps.—It will be manifest that no work can be conducted under ground without artificial light. The simplest light is derived from small tallow candles; and, for many reasons, this is the most convenient and most economical

where there is no danger of the contact of open flame with inflammable gas. Formerly, indeed, all the ordinary work of a mine was conducted by these candles; and, in case of an accident, a clumsy, inefficient, and dangerous contrivance was adopted, called the *steel mill*, by which a faint light was produced by the striking of a rim of steel against a flint. There can be no doubt that explosions have occurred from the use of this instrument.

In the year 1815 was introduced the contrivance, since well known as the Davy Lamp. It is a lamp surrounded with wire-gauze, of a certain degree of fineness; allowing the air to pass freely, and only intercepting a portion of the light, but having the spaces between the wires too small to permit the flame of an explosion to pass.* Theoretically, under most ordinary circumstances, this lamp is perfect. It will, however, set fire to explosive mixtures of certain gases, and will allow flame to pass through, when either the flame is driven through the gauze with a blast, or the lamp is moved very rapidly, producing the same effect. The heated gauze may also occasionally set fire to minute fragments of bituminous coal floating in the air, and adhering to the sides of the lamp. Generally, however, no instrument can be more useful; for it possesses the advantage of simplicity to a high degree, can be made very cheaply, and is not heavy. Many other ingenious contrivances have been suggested—all, no doubt, improvements, in one sense, of the Davy, but none of them so universally applicable. The *Geordie*, as it is called, has a glass defence outside an ordinary Davy; and this form, adapted by Mr. George Stephenson the engineer, is still used in the Killingworth pit, where he worked.

The *Mueseler* lamp, highly appreciated in Belgium, is greatly more complicated than the Davy, and has not been much used in this country. A part of the gauze is replaced with glass, and there is a small chimney within the lamp, preventing explosions of a dangerous atmosphere from taking place inside. More light is given, but the lamp is heavy, and seems likely to get out of order.

The introduction of the Davy lamp, as an ordinary light for fiery mines, is a matter of great importance; and it requires to be considered first whether it is practicable—secondly, whether it would be absolutely effectual—and thirdly, whether, even if not absolutely effectual, it is still on the whole advisable. These are all points that ought to be carefully investigated; since, if advisable, then it is clear that the use of the lamp should be generally enforced, under heavy penalties. Let us consider the chief circumstances of the case:—

It is certainly practicable. In the Wallsend pit there were, at one time, one hundred and thirty Davies in constant daily use. It is true that they show a slight diminution of light as compared with candles; but this is not sufficient to prevent the men from preferring to work with the Davy at the same wages where the coal is more easily broken (more *tender*) in consequence of the pressure of the roof on the pillars. In some of the Prussian and Belgian mines, and in one (the Walker colliery) in the Newcastle district, no open lights whatever are used. In neither case have accidents happened which could not be at once satisfactorily explained; and in the mines on the Saare, in Germany, which are very fiery, several hundred safety-lamps have been in use for

* The cause of this is easily understood. When the flame impinges on one side of the gauze, the heat is rapidly conducted through it; but owing to the large quantity of surface exposed, the radiation is also extremely rapid, and the outer surface is cooled down below the point sufficient to ignite the inflammable air. When the mixture of gases includes olefiant gas—or sulphuretted hydrogen, which burns at a lower heat—the explosion may pass through, and an accident occur; but these cases are extremely rare.

twenty-two years, during which time only two explosions have occurred. In one of them three meshes of the gauze had been destroyed by the heat; in the other, there had been a fall of the roof of several tons, which had broken the lamp.

To use Davy lamps entirely, in fiery mines in the Newcastle coal fields, would also be a very trifling expense; not, indeed, amounting to more than a few hundred pounds a year in any mine. All that is needed is an ample supply of good lamps; a few quick-sighted steady men to give out the lamps to the hewers, and lock them after examining each gauze, and to receive them at the close of the work. The regulations in the Wallsend Colliery are sufficient to show the perfectly practicable nature of an arrangement of this kind, and are produced here as a useful illustration.

ORDERS RESPECTING THE DAVY LAMPS IN USE AT WALLSEND COLLIERY.

1. No workman of any description, whether overman, deputy, hewer, or any one whatever, is allowed to use a lamp in the broken, without its having been previously examined and locked by the lamp-keeper or deputy.

2. No one having charge of a Davy lamp is allowed to interfere with it, in any way whatever, beyond the necessary trimming of the wick.

3. Should any accident happen to the lamps whilst in use, by which either the oil is spilt upon the gauze, or in any other way rendered unsafe, they are to be immediately taken to the Davy boy at the station appointed by the viewer of the colliery, and not again used until they have been properly cleansed and examined by the lamp-keeper or deputy.

4. In case of any sudden discharge of gas, by which the lamps may become filled with fire, it is strictly ordered that all lamps are to be instantly withdrawn, and not again introduced until the workings are pronounced safe by the overman or deputy in charge of the pit.

5. In case of any person having charge of a Davy lamp losing his light, he is immediately to take it himself to the Davy boy, and is not allowed to send it by any other person, and is not to remove any of the stationary lamps in the going boards, as that will deprive the putters of their light.

6. Smoking tobacco is strictly prohibited in the broken; and persons wishing to smoke must come to the out-by side of the lamp station, and on no account attempt it in the workings.

7. No candle or naked light to be taken nearer the broken than the lamp station.

8. No putters, way-cleaners, stone-lads, drivers, or others, are, under any pretext whatever, to carry a lamp during their work. A sufficient number of lamps will be hung in the going boards and wagon-way, to prevent the necessity of boys carrying lamps.

9. It is particularly requested that any person witnessing any improper treatment of the lamp, or any other infringement of these orders, by the boys or others, will immediately give information to the overman or deputy in charge of the pit; and as information of any neglect or improper treatment of the lamp is absolutely necessary for the better protection against accident, a reward of ten shillings will be paid by the owners to the informer, on the conviction of the offending party.

10. Any person being convicted of breaking any of the above rules, to be summoned before a magistrate, or discharged, at the option of the viewer of the colliery.

But, in the next place, it will be asked whether the use of the Davy lamp is an absolute safeguard; and this question must be answered in the negative, since, as we have already seen, accidents may possibly occur, in two or three ways, even if the Davy is in good condition, and is being fairly used. Sir H. Davy himself was aware of, and stated this fact.

The circumstances under which the lamp is liable to accident are, however, these: —1st. Exposure to a jet of gas, whether explosive or pure, after the carbonic acid gas at the bottom of the lamp has been removed. This is readily illustrated by forcing the gas issuing from a common street pipe through the sides of the lamp in a burning state. 2nd. Exposure to a mixture of sulphuretted hydrogen, of pure hydrogen, or of olefiant gas, with the light carburetted hydrogen, as it is commonly found in mines.

It is said by some chemists that these gases are occasionally present in coal mines; but we have the authority of Henry, Thomson and Davy, and more recently of Professor Graham and Dr. Lyon Playfair, for stating that they are not found in the explosive gases of the north of England, or elsewhere as examined by them. 3rd. By the burning of small fragments of coal adhering to the gauze. This is rather assumed as possible than distinctly known. It was tried by Davy with street gas, but the result was doubtful. 4th. By the falling of fragments of coal, &c., from the roof, and consequent breaking of the lamp. These are all cases in which the Davy lamp may, it is said, be the means of causing an accident from explosion; and some of them would be avoided by the use of the improved lamps of various kinds. On the other hand, it may be said that the experiments made by mixture of street gas with common air are not altogether satisfactory, since the gas produced from the distillation of coal is more explosive than common coal gas in mines, and is explosive at lower temperatures. This was distinctly shown by Davy with reference to the particles of coal and pyrites floating about in the atmosphere of the mine. It requires that careful comparative experiments should be made with specimens obtained from mines, in order to determine this and other points of the same kind.

With regard to the relative value of the different safety lamps that have been introduced, the shielded Davy may be said still to keep its place. In its great simplicity, its proportions and portability, and in its being the best known to the miner, this lamp must be considered to possess many advantages over any other; and it may be doubted whether a greater degree of safety is really and effectually produced by any other contrivance. It has been now used for nearly forty years, and in almost every case where danger was known—and how frequent these cases are those only are aware who have visited the mines themselves. It has been trusted implicitly, even to folly, by the superior officers of the mines, in thousands and tens of thousands of doubtful cases, and where it was well known that explosive mixtures existed. In by far the greater number of the two hundred pits in the Newcastle coal fields, the proper officer proceeds at least once every day, with this instrument, through the districts actually worked, before they are visited by the men; and every week or fortnight through the rest of the mine where the gas is most likely to accumulate. And if occasionally—and it is a very rare case—there has been an explosion where no other cause could be fairly assigned than the Davy lamp, we ought not to leave out of consideration the innumerable instances in which it has proved itself to be, when properly used, a sufficient safeguard.

Effect of Weather and Season on Explosions.—Explosions in coal mines from fire-damp have, for many years past, become of serious importance, from their frequency, and the large number of lives often sacrificed. They occur in all our coal fields, and are certainly not less numerous now than formerly. Any facts concerning them are interesting, and may be important; so that the following details of upwards of one hundred recorded explosions may be acceptable. Of these explosions, eighty-two happened on four days of the week, and nineteen only on the remaining three; the order being as follows:—Tuesday, twenty-five; Friday, twenty; Monday, nineteen; Thursday, eighteen; Saturday, eight; Wednesday, six; and Sunday, five. Out of sixty-three whose dates are known, twenty-nine occurred in the four months from September to December, both inclusive; and thirty-four in the remaining eight months. Out of thirty, as many as twenty-three were when the wind was either N.W., W., S.W., or S., and only seven when the wind was from the remaining quar-

ters; most of these (five out of the seven) being when the wind was S.E. Other statistical facts have been recorded, but no general conclusion seems derivable.

But coal mine accidents are not confined to explosions; and water as well as air becomes sometimes a dangerous enemy.

Accidents from Water.—As an instance of this, in the year 1815 seventy-five persons were drowned in the Heaton Main Colliery; the old workings of another colliery in which the water had accumulated rushing into the works, which were carried on in ignorance of the proximity of these old mines. Accidents of this kind have also frequently happened in other coal fields; and it is only a few years since one of the principal collieries of Whitehaven, carried on under the bed of the ocean, was suddenly and completely destroyed by the incursion of the sea into the workings.

One of the most important of the accidents of this kind on record occurred in 1833, in an extensive Scotch colliery, of which the workings were so much injured by the irruption of a river into them as to be afterwards almost useless.

On the 20th of June, in the year above mentioned, two gentlemen fishing in the river Garnock, observed nearly opposite to where they were standing a slight eruption, which they supposed at first was occasioned by the leap of a salmon; but a gurgling noise which succeeded led them to suspect that the water had broken into one of the coal mines surrounding the spot. With this idea they hastened to the nearest pit-mouth to give warning; but their notice was neglected, as too improbable to be worth attending to. Before long the workmen were found to be making their way to the bottom of the shaft, several of them being up to their necks in water when they reached it. All of them, however, escaped with life; and as soon as they reached the surface, they proceeded to check, if possible, the rush of water into the mine, by filling the cavity in the bed of the river with straw, clay, &c.; but their efforts were vain, for the water continued to pour in steadily till the following afternoon, when a large space of the bed of the river was broken through, and the whole body of the stream was in a short time engulphed, its bed being left dry for more than a mile. The river was affected by the tides, and this engulphment took place at low water; but as the tide rose, the sea entered with prodigious force, and the sight was impressive beyond description; the water continuing to pour in, till the whole works, extending for many miles, were completely filled, and the river resumed its ordinary appearance.

No sooner, however, had this taken place, than the pressure of the water in the pits became so great, that the confined air which had been forced back into the high workings, burst through the surface of the earth in a thousand places, and many acres of ground were seen to bubble up like the boiling of a cauldron. Great quantities of sand and water were also thrown up like showers of rain, during a period of five hours; and an extensive tract of land was laid under water, by which from five to six hundred persons were entirely deprived of employment.

Miscellaneous Accidents.—Many other accidents occur besides those of fire and water, and some of them are occasionally fatal; but as they are, for the most part, dependent on local circumstances, and must be looked on rather as ordinary casualties, which cannot be entirely prevented, and belong more or less to all kinds of employment, I shall not here detain the reader by dwelling upon them.

Those connected with the imperfection of machinery—such as the bursting of steam boilers, the breaking of ropes, disarrangement of the winding machinery, and others—are gradually becoming fewer, and, with proper care, may be reduced to a very small number; but as long as coal mines continue to be worked, so long will there be a suc-

cession of victims to the fire-damp, a—"monster" which no art of man is ever likely to render harmless.

Importance of Coal.—It can scarcely be necessary to point out to the reader the vast importance of coal in all parts of the world, and the interest of every one to discover and make use of such stores of wealth, when they exist beneath the surface of the earth.

In a country like England, deprived of any large quantity of wood by the advance of civilization and the replacement of forests by corn fields, where should we obtain means for enduring the inclemency of the weather, or enjoying any comforts at our homes, if it were not for the supplies of this material, conveyed along our shores by numerous ships, and transported by every train on our railways?

But we must look farther. Where would be our manufactures—where would be our iron, the staple of all manufactures, if there were not abundant and cheap supplies of valuable fuel where the ores of these metals occur?

Without coal, could this country have advanced beyond its condition many centuries ago—could there have been education—could there have been printed books available for the multitude—could there have been food and raiment for ourselves—or could science have advanced? Must not England have remained in the back-ground, its inhabitants unable to exercise that intellectual activity which they have exerted in placing their country in advance of the whole world?

Without coal there could have been no extensive use of steam, even if the vast power of that agent had been discovered. Without steam and iron, where should we now be in the advance of civilization over the world? Coal is indeed the indispensable food of all industry. It is a primary material, by whose aid we engender force, and obtain power sufficient for any purpose that has yet been imagined.

Marvellous indeed are the results obtained on considering the uses of those materials which form together the great carboniferous series of deposits as developed in the north of England. In a small strip of country, in an area of less than six or eight thousand square miles, which in some parts of Europe would be passed over almost without remark by the practical man, the politican, and the statistician—we find grouped together a multitude of large towns, a population of some millions of people, having, perhaps, more influence on the comforts of civilized man throughout the world than could elsewhere be found in a space of five, or even ten times that amount. Nor is this all. The other great manufacturing and commercial towns of England, with the exception of the capital, are similarly placed with reference to geological position. The coal and iron of the carboniferous rocks form still the magnet towards which the other desirable things of this world are attracted, and they determine the growth and well-being of towns, not only in England, but elsewhere on the continent of Europe, and lately in America also. In France, Belgium, and Germany, we everywhere see towns rising up into manufacturing importance, where fuel and iron exist beneath the soil; and rarely indeed has it been found possible to produce any great improvement in these respects, except where nature has pre-ordained it by giving these sources of true riches. It is now well known that, however valuable in themselves other rarer natural products may be, there is no doubt of the enormously greater benefit to a people in the case of those materials which either enter into every manufacture, and are sources of power, or which are greatly increased in value by being subject to many processes to render them more generally useful, without, at the same time, causing them to be taken out of consumption.

Dangers of Coal Mining.—Coal in this country is obtained at a serious expense and risk of human life. It often happens that, on taking up a newspaper, we see notice that another explosion from fire-damp has taken place in some coal mine, and that ten, twenty, fifty, or a hundred of the workmen have been hurried unprepared into eternity. Some we read—and these are not the greatest sufferers—have been destroyed at once, burnt to death by the explosion itself, so that no human power, no system could, perhaps, have saved them. But a larger proportion have been found at a distance. They were performing their task some hundred yards off; they heard the shock; they felt that they were doomed men; they rushed at once to the pit bottom, but, cut off by the want of a direct communication, their only chance was to reach the main gallery, and try if, by any happy accident, they might escape. But the moment they arrived at this point, they found the effects of the explosion, the fearful after damp already on its way before them. They are stopped by this invisible, intangible, but fatal and impassable barrier. Some throw themselves upon the ground, and creep on for a few yards in the vain hope of escape. Some, in hopeless despair, await the advance of destruction. Such is a simple history of the whole event. One single inspiration of the after damp produces convulsions in the throat, and is the almost certain precursor of instant death, so that it rarely happens that any person escapes to tell the sad tale. Is it not a question, then, worthy of consideration whether, by any method that could be adopted, these lives might be preserved? For whom do these men suffer? Their widows and orphans, their mothers, their sisters, and their friends have a right to call upon every one of us who benefit by their labours, but take no thought of their dangers and sufferings. They labour for our benefit. We induce them to run these risks, and are bound to weigh carefully the great social relations which impose it as a duty upon us to improve their condition. Each event of this kind concerns us all, and we are all, without exception, responsible in our degree; for if a sufficient interest was felt and expressed in this matter, it would not be allowed to go on as it does from accident to accident. That the subject is obscure and difficult, is not a sufficient reason that it should be neglected; and because the sufferers are patient, the place of the accident far removed, and the objects of it beyond the sphere of our immediate exertions—because few amongst us have visited a coal mine, and know nothing of the danger personally, we are not therefore at liberty to let the matter take its course without an attempt to do good. Some pity should be felt and some sympathy also expressed for those whose lives are spent, and whose deaths may be caused in providing us with the means of comfort and enjoyment. Let us think seriously how much we owe to them—the comfort of the fireside, that essential requisite to home enjoyment—the luxuries that surround us—the facilities of travelling—the use of and interest in all machinery and manufactures—all these we owe to the coal miner; and then think how little we do for him in return. He must daily descend some hundred yards into the bowels of the earth, traversing many miles of low subterranean passages, performing his task in the most inconvenient posture, in an atmosphere always impure and choked with dust, if not actually dangerous—lighted by a small candle, or by the yet fainter glimmer penetrating the meshes of a wire gauze—and then, from time to time, exposed to the chance of these accidents. He troubles not our repose—the tale of his distress hardly reaches our ears—he is poor—he is far away—he dies:—but he is our fellow creature and our fellow countryman. Each one amongst us is related to him by many bonds, and it is our duty to see that every practicable method is adopted to improve his condition. And if the dangers that

surround him must still remain, in spite of all our exertions—if the terrible accidents from explosion must sometimes occur, still we have a duty to perform, for we are bound to use every means to diminish their frequency and extent, and to take away, if possible, from their frightful results. This duty is one, not only affecting the legislature, but every individual amongst us; for all may in some way, either directly or indirectly, have influence with those upon whom ultimately the responsibility of so great an act of public justice must fall.

MINING IN STRATIFIED ROCKS AND ALLUVIA.

Mining operations are of two very distinct kinds, according as they refer to deposited minerals, or to those segregated from various rocks into mineral veins. We have already, at some length, considered the case of coal, which belongs to, and represents, the former class; but it remains to give some account of other substances similarly circumstanced. By far the most important of these, in annual money value, are the iron ores already alluded to. Next to these are streamings for gold and tin, and such mechanical contrivances as are required for obtaining salt from beds of rock-salt, and diamonds, and amber, &c., from their respective alluvia. The question of gold is one that will need some detail. The others are quickly disposed of, as far as they are geologically interesting.

Gold Mining.—It is hardly possible to imagine any subject of general information more calculated to excite attention than that of a new and abundant supply of gold, the representative—generally admitted to be the best—of all kinds of property, and the universal medium of exchange, wherever it is possible, in civilized countries.

Any great change, in value, in this medium—any change in quantity, by which such value may be affected—any new discovery of districts where the quantity is likely to be very large and very easily obtained, offers a legitimate source of interest and excitement, and becomes matter of general conversation.

But when we are told of a country, now first discovered to abound in gold to such an extent that a man can, in a short time, pick up and make his own as much as he pleases, we may well be astonished, and may fairly indulge in not a little scepticism on the subject. We ought, at any rate, to look about us, and learn what has hitherto been the state of the case, and how far our own interests, as possessing some of this kind of property, are likely to be affected.

Within the last few years men's minds have been almost unsettled, and their credulity severely tried, by accounts first from the West coast of North America, and afterwards from Australia, of the existence of deposits of gold so abundant, that a man, with a spade and a few of the simplest tools, can obtain large quantities from the bed of a stream. We read in the local newspapers that the supply seems inexhaustible, or, at least, that it is only limited at present by the number of men at work—that each man may realize a handsome fortune in a few weeks—and that, as far as appearances go, the quantity will increase when what are called the sources of the supply are met with.

Distribution of Gold.—Although there is much that is visionary and extravagant in all this, still there is also a foundation of reality. Of all metals, gold is, with the exception of iron, the most widely diffused over the earth; but it differs from iron in being found only in a native state. It also differs greatly from iron and most other metals in the mode of obtaining it, since almost the whole supply is from alluvial sands, from which it is separated chiefly by washing. Almost every country in Europe, and indeed throughout the world, has yielded gold at one time or other; but each, in

succession, has after a time become drained, and the proportion of the precious metal has been found too small to be worked with profit. England, Scotland, Wales, and Ireland; France, Germany, Spain, and Portugal; Bohemia, Hungary, and Transylvania; Greece and Turkey, besides Russia, have all been amongst the gold-producing countries; but the only parts of Europe in which now there is any activity, are Hungary and Transylvania. In Asia, Siberia, India, China, Japan, and the Indian Archipelago; in North America, almost all the eastern states of the Union, and latterly Canada, besides California; in Central America; and in South America, Brazil, and the whole country on the east of the great mountain chain of the Andes, and its continuation as far northwards as the termination of Mexico—these all have been celebrated; while various parts of Africa, especially on the western shores, abound in the rich deposit. Lastly, but chiefly, Australia has entered the field, and bids fair to send, for some time to come, a quantity at least equal to that from any other tract of the same dimensions. So much have the supplies increased, that whereas, during the ten years preceding 1850, the average yield of the whole gold-producing countries could not be estimated at more than eighty thousand pounds weight; the annual supply from Australia and California alone (at that time not known to contain available gold) has since been considerably more than four times this amount.

Gold washings are at present carried on chiefly in Siberia, California, and Australia; the two latter countries yield by far the largest quantity; but the work in the former is more systematic, and far less costly, so that poorer sands are exposed to the various mechanical operations. The matrix, or earth in which the gold occurs, varies in different countries, but is usually confined to some one or two distinct beds of gravel, often of considerable geological age compared with the surface soil, and spread over a wide tract. The gold, originally contained in veinstone of some kind (often quartz), or disseminated through rocks in a native state, has been washed out of these materials by a long continued exposure and the abrasion of one particle against another. The gold being the heavier substance has been left behind, when, from the action of water, the fragments of rock have been washed away; and thus it chiefly abounds in hollows or other receptacles, where it was not exposed so much to aqueous action, and finally became buried.

In Siberia there are but few localities where the gold washings are largely carried on, and in each of these the metal is disseminated in a quartzy sand, or gravel, containing much oxide of iron. It is not confined to the valleys, but extends even to the hill tops and escarped sides of mountains, proving that the process of accumulation has been a very long one, and commenced when the present mountain chains were entirely below the surface of the water. In Brazil, as in Siberia, where the observations on gold mining are more carefully made than in California and Australia at present, the gold lies in a stratum of pebbles and gravel immediately incumbent on the solid rock, and the excavations of the washers in this gravel are often from fifty to one hundred feet wide, and eighteen to twenty feet deep. The author has seen larger and deeper excavations than these in the mining districts of Eastern Virginia, where also much gold has been obtained. The African gold is entirely got from the beds of rivers, partly on the gold coast, partly in Abyssinia, and partly on the Mozambique coast, and the same may be said of Asia and the Asiatic islands.

It is needless to repeat here what has been so frequently and prominently stated concerning the position of the gold in California and Australia; and, indeed, descriptions of auriferous detritus have little value, as they could hardly lead to the re-

cognition of similar material in a new district, or suggest discoveries in a country where the existence of gold was not previously known. We proceed to the more practical and useful considerations connected with the working of such ores when found.

Mechanical Process.—The examination of rocks suspected to contain gold is a very simple matter, although the most convenient mode of obtaining the precious metal from the associated sand, mud, or gravel, necessarily involves mechanical contrivances, and requires some consideration. When a rock is supposed to be auriferous, or when the sands or other alluvial matter of a district are to be examined for gold, the rock should first be pounded fine, and sifted:—a certain quantity of the sand thus obtained must be washed in a shallow iron pan, and as the gold sinks, the floating mud should be allowed to pass off into some receptacle. The largest part of the gold is thus left in the angle, or lowest point of the pan; by a repetition of the process a further portion is obtained; and when the bulk of sand is reduced to a manageable quantity, the gold, if in too small a proportion to be readily removed (or the residuum in the latter case, after the richer particles have been carried away), is amalgamated with clean mercury. The amalgam is next strained, to separate any excess of mercury, and is finally heated and the mercury expelled, leaving the gold. In this way, by successive trials with the rock, the proportion of gold is quite accurately ascertained. Where the rock or gravel is rich, the amalgamation is unnecessary in a first trial, sufficient being obtained at once to give a profit without any further process than simple washing.

Masses of quartz, with no external indication of gold, examined in the above way, will sometimes yield at the rate of about five ounces of gold to a ton of sand or gravel.

Washing.—The methods adopted on a large scale, to separate gold from such alluvial soils as contain a sensible proportion of this valuable metal, vary according to local circumstances and the tools that may be at hand. Washing on inclined tables is sometimes followed with advantage, as in Hungary, where a long plank is employed with a number of transverse grooves cut in its surface. This plank is held in an inclined position, and the sand to be washed put in the first groove; they then throw water on it, when the gold mixed with some of the sand collects usually towards the lowest furrow. This mixture is removed into a flat wooden basin, and by a peculiar movement of the hand the gold is separated entirely from the sand. The stony ores are first pounded in a stamping-mill.

Amalgamation.—With the poorer ores, such as the auriferous sulphurets, whether of copper, iron, or lead, it is usual to adopt the process of amalgamation, either after roasting or without submitting them to that process. This method, however, belonging strictly to metallurgy, will not be described in this place, since at present the mechanical processes of separating the metal form the subject under consideration; and as in the Brazilian gold district the processes adopted include most of the mechanical contrivances that have been from time to time introduced, our examples will be chiefly drawn from that country.

Brazilian Methods.—At the commencement of the mining* system in the Brazils, the common method of proceeding was to open a square pit, till they came to the

* The word "mine," in the signification attached to it by the inhabitants of Brazil, conveys a different meaning to that which it imports in Europe. Whilst in the latter it designates a subterraneous excavation, in the former it is simply applicable to the bed of a river, the bottom of a ravine, or some place of greater or less extent, where the soil is composed of alluvial matter, containing metal.

*cascalho;** this they broke up with pickaxes, and placing it in a wooden vessel, broad at the top and narrow at the bottom, exposed it to the action of running water, shaking it from side to side, till the earth was washed away and the metallic particles had all subsided. Lumps of gold were often found from two and a-half to twelve ounces in weight, a few which weighed twenty-five to thirty-eight ounces, and one it is asserted weighed thirteen pounds; but these were insulated pieces, and the ground where they were discovered was not rich. All the first workings were in the beds of rivers, or in the table-land, or flat alluvial banks over which the streams had at one time flowed.

In 1724, the method of mining had undergone a considerable alteration, introduced by some natives of the northern country: instead of opening the ground by hand, and carrying the cascalho thence to the water, the miners conducted water to the mining-ground, and, washing away the mould, broke up the cascalho in pits under a fall of water, or exposed it to the same action in wooden troughs; and thus a great expense of human labour was spared.

The mode of working the mines of Jaragua is more simple, and may be easily explained. Suppose a loose gravel-like stratum of rounded quartzose pebbles and adventitious matter, incumbent on granite, and covered by earthy matter of variable thickness. Where water of sufficiently high level can be commanded, the ground is cut in steps, each twenty or thirty feet wide, two or three broad, and about one deep. Near the bottom, a trench is cut to the depth of two or three feet; on each step stand six or eight negroes, who, as the water flows gently from above, keep the earth continually in motion with shovels, until the whole is reduced to liquid mud and washed below. The particles of gold contained in this earth descend to the trench, where, by reason of their specific gravity, they quickly precipitate. Workmen are continually employed at the trench to remove the stones and clear away the surface, which operation is much assisted by the current of water which falls into it. After a few days' washing, the precipitation in the trench is carried to some convenient stream to undergo a second clearance. For this purpose wooden bowls are provided, of a funnel shape, about two feet wide at the mouth, and five or six inches deep. Each of the workmen standing in the stream takes into his bowl five or six pounds weight of the sediment, which generally consists of heavy matter, such as granular oxide of iron, pyrites, ferruginous quartz, and often precious stones. They admit certain quantities of water into the bowls, which they move about so dexterously, that the precious metal, separating from the inferior and lighter substances, settles to the bottom and sides of the vessel. They then rinse their bowls in a larger vessel of clean water, leaving the gold in it, and begin again. The washing of each bowlful occupies from five to eight or nine minutes. The gold produced is extremely variable in quantity and in the size of its particles; some of which are so minute that they float, while others are found as large as peas, and not unfrequently much larger. This operation is superintended by overseers, as the result is of considerable importance. When the whole is finished, the gold is placed over a slow fire to be dried.

It is considered that the tedious process of washing might be much shortened by

* This is the name locally given to the auriferous detritus. The common cascalho of the country is an indurated soil in which gold is contained, and seems to consist of the fragments of veins which have been by some means broken up, rolled about by the action of water in agitation, and buried by it among the clays which have composed its bed. There is, however, a difference between the auriferous gravel in the mountains and that in the rivers: the imbedded stones in the mountain cascalho are rough and angular, but in that of rivers they are rounded.

using a machine of very easy construction; such as a cylinder, formed of bars of iron, longitudinally placed, and nailed to circles of wood, open at each end, and suspended on two centres, one about sixteen inches higher than the other. At the highest end the ore is put in by means of a hopper which communicates with it. The bars must be nailed almost close to each other at the upper end, gradually widening to the lower end, where they should be almost half an inch asunder. The cylinder ought to be from ten to twelve feet long, and a stream of water conducted to fall upon it lengthwise; it should be enclosed like a dressing-machine in a flour-mill, and be subjected to a very quick motion. The portion of ore containing the most gold will fall through near the upper end; the other parts, according to their comparative fineness, gradually descending until nothing but the pebbles fall out at the lower end; the earth, &c., falling into partitions or troughs below the cylinder, would be ready for being separated from the gold by hand, which might be done with very little trouble. Machines of this kind might be made on any scale, and if generally known and adopted, would save human labour to a very great extent. A further improvement might be made, too, in this useful apparatus; for if the gold washed from the machine were to fall upon troughs placed in an inclined position, having a channel across about a yard from the upper end, all the gold would precipitate into it; and if a man were to be continually employed in agitating the water, the earthy matter would run off, leaving only the gold and the ferruginous particles, which might be separated by mercury. Other ingenious and more complicated contrivances are known, and have been adopted successfully in Siberia, but are not adapted to countries where labour is costly.

Tools.—The only miners' tools employed in Brazil up to a recent period were the iron-bar and the hoe, but the common miner's pick would in many cases be serviceable; and *bucking-irons* * would reduce the matrix much more effectually than beating it with stones. In many instances, hand-sieves, if not too costly, would be found extremely useful, and would certainly save considerable time and labour in washing.

Crushers.—Mills composed of heavy irregular stones, resembling those used in England for grinding flints, are useful in reducing many of the ferruginous masses and softer substances which contain gold; whilst stamps might be employed where the gold is found in hard and brittle substances; or these would be perhaps as effectually, though more expensively, pulverised by a heavy stone rolling on its edge and worked by men. †

Californian Methods.—The mining operations in California are, as may be supposed, on a somewhat rude scale at present, and there cannot be a shadow of doubt that large quantities of gold are allowed to escape the washings. These, however, will not travel far, and may reward, though in a smaller degree, those who carry on operations after the first fever of gold-seeking has passed away. A good idea will be formed of the first proceedings by the following extract from an official account:—"The day was intensely hot, yet about 200 men were at work in the full glare of the sun; washing for gold—some with tin pans, some with close-wove Indian baskets; but the greater part had a rude machine, known as the cradle. This is on rockers, six or eight feet long, open at the foot, and at its head has a coarse grate, or sieve; the bottom is rounded with small cleets nailed across. Four men are required to work this machine;

* Bucking-irons are pieces of cast-iron, with wooden handles, used at the lead-mines in Britain, to break the ore from what it adheres to.

† Iron cylinders hardened at the surface by sudden cooling are used in Cornwall in crushing tin ores, and might be very useful if available.

one digs the ground in the bank close by the stream; another carries it to the cradle, and empties it on the grate; a third gives a violent rocking motion to the machine, while a fourth dashes in water from the stream.

"The sieve keeps the coarse stones from entering the cradle, the current of water washes off the earthy matter, and the gravel is gradually carried out at the foot of the machine, leaving the gold mixed with a heavy fine black sand above the first cleets. The sand and gold mixed together are then drawn off through auger-holes into a pan below, are dried in the sun, and afterwards separated by blowing off the sand. A person without a machine, after digging off one or two feet of the upper ground, near the water (in some cases they take the top earth), throws into a tin pan or wooden bowl a shovelful of loose dirt and stones; then placing the basin an inch or two under water, continues to stir up the dirt with his hand in such a manner that the running water will carry off the light earths, occasionally with his hand throwing out the stones; after an operation of this kind for twenty or thirty minutes, a spoonful of small black sand remains; this is placed on a handkerchief or cloth and dried in the sun, and the loose sand being blown off, the pure gold remains."

The iron-bar, the pick and the shovel,* are all the tools that can well be needed by the solitary miner to raise the alluvial soil that seems to be so amply supplied with the precious metal. The chief operation requiring mechanical ingenuity is, therefore, the *washing*, or removing the useless soil, and this may be done either before or after the reduction of the whole mass to powder. No doubt, where the gold is in tolerably large lumps, the former is the more productive, because less time is wasted; but nearer the mouths of the streams, and in that material which has already been coarsely sifted, there will remain a large quantity of very rich produce, that can only be obtained by pounding as well as washing.

The following method is adopted in Chili to reduce auriferous detritus to a fit state for washing:—A streamlet of water conveyed to the hut of the gold-washer is received upon a large, rude stone, whose flat surface has been hollowed out into a shallow basin, and subsequently into three or four others in succession. The auriferous particles are thus allowed to deposit themselves in these receptacles, while the lighter earthy atoms, still suspended, are carried off by the running water. The gold thus collected is mixed with a quantity of ferruginous black sand and stony matter, which requires the process of trituration. This is effected by a very rude and simple grinding apparatus, consisting of two stones, the under one being about three feet in diameter and slightly concave. The upper stone is a large spherical boulder of granite, about two feet in diameter, having on its upper part two iron plugs fixed opposite each other, to which is secured, by lashings of hide, a transverse horizontal pole of wood about ten feet long. Two men, seated on the extremities of this lever, work it up and down alternately, so as to give to the stone a rolling motion, sufficient to crush and grind the materials placed beneath it. The washings thus ground are subjected to the action of running water, upon inclined planes formed of skins, by which process the silicious particles are carried off, while a portion of the ferruginous matter, mixed with the heavier grains of gold, is extracted by a loadstone; it is again washed till nothing but pure gold-dust remains. The whole process is managed with much dexterity; and if there were much gold to be separated, it would afford very profitable employment; but generally the small quantity collected is sufficient only to afford subsistence to a few miserable families.

* The miner's form of the shovel is the best, consisting of a simple pan of a conical form.

More elaborate contrivances, moved by horse-power or by water, would amply repay the cost and labour of erection; and the following account of the mechanical contrivances in use in England and other mining countries for the ores of other metals (such as lead, copper, and tin), will perhaps suggest useful hints, even if the methods are not exactly copied.

Stamps.—The instruments for preparing ore in most mining districts are principally stamping-mills, or *stamps* as they are called, crushing-mills or grinders, and jigging-machines. The former are of various dimensions and power; they are usually driven by water-wheels, and are generally sufficiently simple in their construction. They consist of sets of pestles working up and down within a box or trough open behind, to admit the ore which slips in under the pestles, being carried along by a stream of water falling over an inclined plane. Each pestle is of wood, measuring about six inches by five in the square, and of convenient length. Each also carries a lifting-bar secured with a wooden wedge and iron bolt, and each terminates below in a lump of cast-iron called the head, which is fastened to it by a tail, and weighs about two-and-a-half cwt. The shank of the pestle is strengthened with iron hoops. A turning shaft is so arranged as to communicate motion by cams placed round its circumference, lifting the pestles in succession by their lifting-bars, and then allowing them to fall through a space of eight or ten inches. They are arranged in such a way in the trough, that one falls while the others are uplifted. There may be four cams for each pestle, and about seven revolutions of the shaft per minute, giving, therefore, twenty-eight stamps per minute from each pestle. Two sets of three or four pestles each, with the trough in which they work, is called a *battery*, and a battery of six pestles will pound about sixty cubic feet of the ordinary tin stuff of Cornwall (weighing perhaps four or five tons) in twelve hours.

In front of the troughs there are openings fitted with an iron frame, the openings measuring about eight inches square. This frame is closed with sheet-iron, bored conically with a large number of holes in the square inch, the narrow side of the hole being towards the inside. The ore passing out by these holes is received into basins, where it is separated by water into several kinds of mud afterwards sifted.

The Crushing-mill, or grinder, consists of one or more pairs of iron rollers placed a very short distance apart, and kept in motion either by the direct action of a water-wheel, or steam-engine, or by cog-wheels attached to it. Immediately above the rollers is a hopper, into which the lumps to be crushed are thrown, when, falling through between the rollers, they are completely broken into small fragments. In some crushing-mills there are two or three pairs of rollers, those below being placed very near together, so as to reduce the stuff falling from above still finer; and by an ingenious application of sieves kept in motion by the machine, the stuff can be sorted into two or three different sizes. Although, by passing through the crushing-mill, the material has been reduced to very small fragments, it is not all sorted; but in the next process, by the jigging-machine, or "break-sieve," this is done to a considerable extent.

The Jigging-machine consists of a wooden frame, open at the top, and provided with a strong screen, or iron grating, at the bottom: it hangs over a cistern of water, being suspended to a long lever, the motion of which alternately plunges it into the water, and raises it out with a peculiar jerk each time. The ores being placed in the sieve, and subjected for a short time to this operation, the heavy metallic pieces settle at the bottom, while the lighter fragments of spar and veinstone are thrown to the top, and every now and then dextrously skimmed off with a piece of board by

a man who stands by. In the operation of jigging, a very important separation is effected, as three products are obtained by it: the small rich particles which pass through the sieve into the cistern below, and are removed occasionally as may be necessary; the larger rich fragments which occupy the bottom of the cistern; and the poor earthy matter which forms a layer at the top. This last product, although poor, still contains too much metal to be lost: it consists of small fragments of rock or veinstone, many of which have particles of metal, either attached to them or intermixed with them, and to any eye but that of the miner's these would appear quite worthless, no less from the small quantity of the ore than the manifest difficulty of separating it from such a mass of stony matter.

To extract the ore from this refuse-matter, several processes are used, which are chiefly grinding between rollers placed very close to each other, stamping to a fine powder by the stamping-mill, and, finally, washing upon an inclined plane. In this operation, the fine metallic mud, or "slime," being carefully spread over the inclined plane at the upper end, a gentle stream of water is allowed to flow over it, which washes the light earthy particles towards the bottom, leaving the heavier metallic ones in a very pure state towards the top. As in this process, and indeed all other operations of dressing in which a stream of water is employed, many of the smallest and most minute particles of the ore are carried away, the waste of which, in an extensive mine, would be considerable, it is arranged that all such water shall pass into successive reservoirs, termed "slime-pits," in which the metallic particles fall to the bottom, and are from time to time collected and subjected to such treatment as to obtain them in a tolerably pure state.

Berdan's Machine.—In addition to these contrivances, many have been suggested from time to time, and tried with various success. As one of the newest, which, from its simplicity and efficiency, has attracted much attention in this country, and has certainly proved very successful, we may refer to Berdan's machine.

This machine consists of a cast-iron pan, or basin, fitted with an axis, and made to revolve in an inclined or tilted position. Two cast-iron balls, or shells, one nearly fitting the basin, and the other much smaller, are placed within it. Near the rim of the basin, are a number of delivery holes, or spouts, provided with wire gauze, which can be so contrived as to secure any required degree of pulverisation. Beneath the basin, and revolving with it, can be placed a small furnace.

The operation of the machine is simple. Being erected in a convenient place, in nests of one, two, or more basins, and steam or water power provided, together with a supply of water for washing, a quantity of mercury is put in each basin, and the basins are made to revolve.

The balls being at first carried up a short distance by friction, immediately roll down towards the lowest point, and are thus made to revolve in a direction opposite that of the basin itself. The mineral is then introduced on the off-side of the larger ball, in sizes not larger than a hazel-nut, and care must be taken that the quantity should not only be regulated by the work the machine is able to get through, but be supplied, with great regularity, by a hopper and feeding apparatus. The water being admitted to flow continually, the excess runs off by the spout holes, carrying with it, as mud, the whole of the earthy matter and the ore that does not amalgamate, as fast as it is reduced to a sufficiently fine powder by the action of the other parts of the balls. When required, the mercury, with the gold in a pasty state, or in solution, can be drawn off by removing a plug.

A contrivance for collecting any mercury that may escape from the spouts is supplied with the machine, and has been found to succeed well in preventing ultimate loss. This *separator*, as it is called, would also collect any stray particles of gold that might escape from the basin, and amalgamate them.

It will be evident from this description, that the processes of pulverising, amalgamating, and washing, take place simultaneously at the lowest point of the basin, in close contact with the mercury; and that the mercury, instead of being spread over a large surface, and subject to be broken into globules, is kept together nearly in one spot. Hence arises a great economy of mercury, and much of the peculiar accuracy of the machine may probably be traced to the same cause.

These machines are made of various sizes. They seem especially adapted to the moderately rich ores, yielding from two or three, to fifteen or twenty ounces to the ton, of which, as may be supposed, the quantity is not very large.

On the other hand, some of the Siberian contrivances, though extremely efficacious as washing machines (not amalgamating), operating on as much as two hundred tons in a day, with the labour of eight horses, twenty men, and six boys, are better adapted for extremely poor sands, of which there is an indefinite quantity obtainable at a very small expense for cartage and the removal of rubbish, and which can be worked where labour is inexpensive.

Tin Streaming.—The operation ot streaming for tin is extremely like that required for gold in auriferous districts; but the resultant material being less valuable, a larger per centage of ore is necessary.

In our own country, the stanniferous gravels of Cornwall are not usually upon the surface, but are either covered with other gravel, or with clay, sand, or peat, which require to be removed before the fundamental rock is reached on which the tin-stones rest. The gravel, when collected, is thrown upon an inclined plane, upon which a fall of water is conducted, and then being worked about, the tin- tones, if of sufficient volume, and provided the force of the water is not too great, remain upon the inclined plane, while the lighter stones and earth are washed away.

It is from this method of separating the ore that such works have been called stream-works. They are of comparatively small importance in reference to the general supply, but still afford employment to a number of the poorer miners.

Diamond Washing.—Diamonds are obtained in India, and elsewhere, by operations which sufficiently resemble mining to justify a description in this place. They occur in gravel generally, near the banks of streams, or in mud-banks, sometimes of great extent, in the district whence they have been generally obtained. In addition to India, South America has yielded a number of these gems, of large size and great value. They have also been found in Siberia, and lately in Australia, and appear to be present very generally where gold alluvia exist.

The process of exploring is exceedingly simple, and the only tool employed is a sharp pickaxe. With this tool the men dig into every promising spot, and deposit on the banks of the river all the mud and sand they get up. There it is looked over by the women and children of the tribes, who, for this purpose, take a plank, five feet in length by two in width, hollowed out in the middle, and furnished with a rim on each side, three inches in height. They place this plank in a position a little inclined (just enough to allow water to run off), heap upon it the mud and sand dug from the river, and continue for some time to pour water upon it. As soon as the water runs away perfectly clear, they anxiously look over the hard stony matter which is left upon

the plank, and pick out all the loose pebbles and larger pieces of gravel; these they throw away, and the remaining mass, consisting of smaller grains, they remove to another plank of the same form as the first, but smaller, and carefully spread it over the surface, so that every particle can be separately examined; this they do one grain at a time, throwing away all that is merely stone or gravel, and laying aside every particle of gold or crystal of diamond. They usually contrive to place the board so that the sun shall shine upon it, at a certain angle, during this operation, by which every particle shall be well illumined. The earth chiefly sought after, and most accurately examined, is a red ochry clay, containing a small proportion of oxide of iron; in this the diamond is most commonly found, though, as it is sometimes met with in the loose mud, the whole is well washed and examined.

Iron Ores.—In a previous paragraph (see page 235) reference has been made to the ironstones of the coal measures while speaking of the minerals associated with coal. The manufacture of iron, and the abundance of iron ores in England, besides the peculiar bearing of this subject on general mining, form a combination of circumstances too important to be left without further reference. We propose, therefore, to give an account of iron ores, more especially those which are found in our own country, as a fit termination to the present notice of mining in stratified rocks. We shall avail ourselves of an admirable account of English iron ores sent to the Great Exhibition of 1851, by Mr. S. H. Blackwell of Dudley, and described by him in the catalogue.*

Wales.—From the area of the mineral field in South Wales, and the great variety in character, both of its beds of coal and its measures of ironstone and blackband, it will, in all probability, long remain the most important iron-making district in the world.

The number of furnaces now in blast is 143, averaging about 100 tons of iron each per week, or a gross annual production of 700,000 tons, and requiring 2,000,000 tons of ironstone, principally furnished from this coal field. In North Wales the production is very limited.

Shropshire.—Annual production of iron about 90,000 tons. This field was one of the first important iron-making districts of the kingdom; but from its limited extent, the production of iron in it has remained, for a considerable period, nearly stationary. The quality which it produces is very good.

South Staffordshire.—The Gubbin and White Ironstones are the principal

* So extensive are the ironstone beds of the coal measures, that they furnish in themselves the greater part of the iron produced in Great Britain; but the reader should be aware that the iron-making resources of the kingdom are by no means confined to them. The carboniferous or mountain limestones of Lancashire, Cumberland, Durham, the Forest of Dean, Derbyshire, Somersetshire, and South Wales, all furnish important beds and veins of hæmatite; those of Ulverston, Whitehaven, and the Forest of Dean are the most extensively worked, and seem to be almost exhaustless. The brown hæmatites and white carbonates of Alston Moor and Weardale also exist in such large masses that they must ultimately become of great importance. In the older rocks of Devon and Cornwall are found many important veins of black hæmatite, and in the granite of Dartmoor, numerous veins of magnetic oxide and specular iron ore. The new red sandstone furnishes, in its lowest measure, beds of hæmatitic conglomerate. In the lias and oolites are important beds of argillaceous ironstones, now becoming extensively worked; and the iron ores of the greensand of Sussex, once the seat of a considerable manufacture of iron, may again become available, by means of the facilities of railway communication.

The produce of the manufacture of iron in Great Britain, in 1750, was only about 30,000 tons; in 1800, it had increased to 180,000 tons; in 1825, to 600,000 tons. In the following year the duties upon the introduction of foreign iron were either removed or rendered nominal, since which the production of iron has nearly quadrupled, being now about 2,250,000 tons.

ironstones of the Dudley district. The former will average about 1,500 tons per acre; the latter varies much both in quantity and richness, but yields about the same average.

In the Wolverhampton districts there are six bands of ironstone, all of extremely good quality, averaging from 30 to 35 per cent. From the low cost at which they are generally raised, the number and variety of the measures both of coal and ironstone contained in so small a space of ground, and the superior quality of the iron produced, this part of the South Staffordshire coal field may be considered as one of the most important, in proportion to its area, of any of our iron-making districts. It is indeed considered to be the second most important iron-making district in the kingdom, for although the production of pig-iron in Scotland is equal to that of this district, yet it far surpasses Scotland in the manufacture of wrought-iron; whilst the superior quality produced also gives it pre-eminence over that of Wales. The annual production of iron is nearly 600,000 tons.

North Staffordshire, although not of great importance *directly*, as an iron-making district, its annual produce being only about 55,000 tons, is remarkable from the amazing extent of ironstone which it contains, and the large quantities sent thence to the South Staffordshire, and the North Welsh iron districts. No other known coal field contains anything like an equal number and extent of ironstone measures. From the Bassey Mine to the Knowles Mine, a series of measures at the Foley Colliery, Longton, of only 250 yards in thickness, there are nine distinct workable measures of ironstone. At Apedale, the Blackband, Red-shag, Bassey Mine, and Red Mine, ironstones are respectively 4, 6, 7, and 9 feet thick. In consequence of so large a proportion of the cheapest worked ironstone measures being Blackband or carbonaceous and also from the inferior quality of its coals, the iron of this district is inferior.

Yorkshire and Derbyshire.—In the northern district the annual production of iron is about 25,000 tons, and the quality of iron very superior. The Low Moor and Bowling marks are especially celebrated. The beds of coal in this district are exceedingly thin; and only one is used for iron-making purposes. The production of the southern district is about 20,000 tons. In Derbyshire many of the beds of ironstone lie in such a thickness of measure as only to be workable to advantage by open work or bell-pits. Where these means of working can be adopted, the produce per acre is oftentimes very large; in the Honeycroft Rake it is 6,000 tons per acre; in the Black Shale 8,000 tons.

Northumberland, Cumberland, and Durham.—The annual production of iron is about 90,000 tons. The iron works of this district are gradually increasing in importance, the cost of fuel being so low as to permit ores to be brought from many different localities. The black bands of Scotland, and of Haydon Bridge, the brown hæmatites, and white carbonates of Alston and Weardale, and the argillaceous ironstones of the lias of Whitby and Middlesborough, are all used for the supply of the iron works of this district.

The *brown hæmatites* deserve especial attention. They are found associated in very large masses, with the lead veins of this district, and occasionally they occur as distinct and regular beds. They contain from 20 to 40 per cent. of iron. Sometimes they exist as "riders" to the vein, sometimes they form its entire mass, and in this case they occasionally attain a thickness of 20, 30, and even 50 yards. Their employment for iron-making purposes is only recent; but the supply of ore which they can furnish is almost unlimited; and when some better means of separating the zinc and lead associated with them may have been discovered, they will, doubtless, be found to be of great importance.

Lancashire and West Cumberland.—The production of iron in this district is very limited; but the quality, charcoal being used for fuel, is very superior, and the produce combines, with the fluidity of cast-iron, a certain malleability, especially after careful annealing. The ore, both of the Whitehaven and the Ulverstone and Furness districts, is raised most extensively for shipment to the iron works of Yorkshire, Staffordshire, and North and South Wales. In quality these ores may be considered as the finest in this kingdom, and the supplies which these districts are calculated to produce are very great. The large per centage of iron which they contain (from sixty to sixty-five per cent.) and their superior quality, also enable them to bear the cost of transport, and they are becoming every day of greater importance. They are found, both as veins traversing the beds of the mountain limestone formation, transversely to the lines of stratification, and also as beds more or less regular. The former is the general character of the Ulverstone and Furness ores, no clearly defined bed being, as yet, known in that district, whilst at Whitehaven there are two, if not more beds, of irregular thickness, but with clearly defined floors and roofs, and oftentimes sub-divided themselves by regular partings. These beds attain a considerable thickness, occasionally twenty or thirty feet. The area over which they extend is not as yet well-known; but they have been worked extensively for many years, and the workings upon them are rapidly increasing. They lie beneath and close to the coal measures, which both furnish the necessary fuel and also important beds of argillaceous ironstones for admixture.

Forest of Dean.—The annual production is about thirty thousand tons. The ores are carboniferous, lying beneath the coal measures; but there is also a bed worked locally in the millstone grit. The limestone ore occupies a regular position in the measures—assuming rather the character of a series of chambers than a regular bed. These chambers are sometimes of great extent, and contain many thousand tons of ore, which is generally very cheaply raised; no timbering or other support for the roof being required. The supply of ore is almost unlimited, and the iron made from it is celebrated for the manufacture of the best tin plate, and always bears a high price. It is raised extensively for shipment to the iron works of South Wales. It was worked at a very ancient date, either by the Romans or the Britons, as is evident from the remains of old workings along the outcrop of the ore bed. This ore averages from 30 to 40 per cent.

Miscellaneous Resources.—Pisolitic iron ores have been found in the old rocks, and have, at different periods, been worked to a considerable extent, for transport to South Wales. They are of inferior quality; but the large masses in which they lie enable them to be raised at a very trifling expense. They are found at Tremadoc, Pwllheli, Caernarvon, Island of Anglesea, and many other localities round the North Welsh Coast, and will, doubtless, at some period, prove of importance, from the great extent to which they are there developed.

Hæmatitic conglomerates are found at the base of the new red sandstone, and generally occupy the position of its lowest bed. Their character, as working ores, is very variable, being sometimes mixed up with so much extraneous material as almost to be worthless; but occasionally they exist in regular beds, and contain so large a proportion of Hæmatite as to become of considerable importance.

The clay ironstones of the lias are only just beginning to add to our iron-making resources. They furnish an instance of the unexpected development of national wealth, arising from the facilities afforded by railroads. Some of these are raised along the outcrop of the beds along the coast from Whitby to Scarborough. The cost of raising

is trifling. Others are from a bed at Middlesborough, whose thickness is very irregular, sometimes amounting to twelve or fourteen feet, but averaging about six feet.

The Northamptonshire oolites also yield very large quantities of an ore of moderate richness, besides a considerable amount extremely rich. All these are at present conveyed by rail to the places where fuel is cheap, and they are not likely to be available in any other way.

Clyde District.—From the valley of the Clyde are obtained supplies of ironstone, of great value—more especially the *black bands*, first discovered and worked in this district to great profit. These rich beds alternate with the coal seams; and from the remarkable facilities offered by the mode of their occurrence, and the peculiar mode adopted in reducing them, an iron is obtained at an unusually low rate.

The Treatment of Ores varies according to the nature of the ore; but may be generally explained in a few words. Those ores which consist chiefly of carbonate of iron require roasting, either in open heaps or in furnaces, in order to expel water, sulphur, and carbonic acid, and render them more porous; but the oxides are more easily managed, and it is usual in England to make an admixture of such ores as will help each other in fusing. When prepared and mixed, the ores are put into the furnace with coke or coal, and with such mineral substances as will combine with the earthy impurities of the ore, whatever they may be, and serve as a flux. Limestone is a common flux when the ore contains alumina and silica, as do the clay ironstones of the coal measures; but when the ore is chiefly calcareous, already including much carbonate of lime, silica and alumina are needed; and thus it becomes advantageous to mix silicious with calcareous ores, in such proportions as to avoid the necessity of flux.

Salt Works.—There are many other substances to which the general principles of mining for coal may be applied, and which, therefore, belong to this part of our subject. It is, however, unnecessary to detain the reader with them, as they involve no new methods. Of these, salt is perhaps the most important mineral; but the usual mode of obtaining it from the new red sandstone of Cheshire, where it is very abundant, is in most respects similar to the ordinary colliery methods of South Staffordshire. There is no danger in these cases of explosive gases; but carbonic acid gas is not unknown.

GEOLOGY OF MINING IN MINERAL VEINS.

Mineral Veins.—The difference is so great between removing portions of a deposited rock, as in coal-mining, and laying out or carrying on those operations by which the common ores of copper, lead, &c., are obtained from mineral veins as to require a separate consideration of this latter subject, and a reference to those points which are essential for success.

A mineral vein has more resemblance to the dykes and faults spoken of in coal mining, and already described, as far as they affect stratified deposits, than it has to the deposits themselves, of whatever nature they be. It may be explained as a crevice more or less vertical, caused by the contraction during drying or metamorphosis, or by the mechanical disturbance of a rock, this crevice having been subsequently filled up. It may or may not be connected with upheaval; it may be wide or narrow, regular or irregular, limited in extent, or ranging very widely; and it may either be easily recognisable or extremely obscure. It is usually occupied with crystalline minerals of some kind, whence its name; but these are only occasionally metalliferous, and it is

not always even when metalliferous minerals occur that they are sufficiently abundant, accessible enough in a convenient chemical condition, or so intrinsically valuable as to be worth extracting. Nor are the contents of veins always crystalline, though it seldom happens that there is a total absence of metamorphic action.

So varied are the appearances put on, even in different parts of our own country, by these mineral veins, and so numerous are the modifications elsewhere, that any minute definition of the term is out of the question. Still it is essential that the student in this department of geology should have some information on which he can rely. The veins differ essentially according to the rocks they traverse; and thus, in giving an account of them, it will be advisable to consider separately those occurring in stratified rocks (such as alternating limestones and sandstones), those in metamorphic schists, and those in granite, basalt, and other rocks chemically arranged.

In altered stratified rocks both copper and lead veins occur; but in this country, and indeed generally, the latter are the most common in limestones and grits, while copper prevails in slates, schists, and porphyritic rocks. The veins of lead ore that are most characteristic occur in the carboniferous rocks of Wales, Derbyshire, Durham, and Northumberland, and are of three kinds, which are technically known as *rake veins*, *pipe veins*, and *flats*. Copper ores occurring in metamorphic schists and granites, are chiefly found in England, in the counties of Cornwall and Devonshire.

Rake Veins are simple crevices crossing all the rocks of a series, generally vertical or highly inclined, and having all the characters of crevices formed in the rock by contraction—a gash or open fissure having thus been formed, which has sometimes, on subsequent upheaval, expanded the gap already formed, or produced a small fault or slip, preventing the two sides of the fissure from now corresponding. Such crevices in England are rather limited in extent; but in South America they have been followed sometimes for more than fifty miles.

There are two kinds of rake veins, one consisting merely of cracks or rents, without any slip or disturbance of the strata—the other including faults, so that the edges, originally opposite, are now at different levels. The latter (*slip veins*), are often twitched—in other words, the intervening space between the walls (or cheeks) of the vein are irregular, sometimes large, and then immediately closed, thus forming a succession of pockets or bellies, which are often filled with ore, but which are separated by intervals where the ore does not exist at all, or is too poor to pay for working. On the other hand, the former (*gash veins*) are more regular, generally rather wider at top than lower down, and often found to close altogether. As an example of the magnitude of veins of this kind, and the extent to which they are sometimes filled with ore, may be mentioned the case of a mine at Llangunog in Wales, which showed for some time a solid rib of galena (lead ore) five yards wide in the middle of the vein. From the workings of this vein, we are told, "The ore was poured out of the kebbles at the shaft head into the waggons, and carried directly to the smelting-house, without being touched by the washers and dressers of ore, besides several feet upon the sides of the vein which was mixed with spar and other stony matter, and went through the hands of the washers."*

This noble vein was cut off below by a bed of black schist, and was never afterwards recovered.

The slip, or throw veins, are less vertical than the gash veins, and are often tolerably regular. They traverse all the strata; but they do so unequally—that is, the

* Forster's Sections of Strata, p. 187.

interval between the walls is very apt to vary in crossing different rocks, and the value of the vein for ore is also greatly affected by the nature of the strata. They contain ore often distributed in threads or strings of various thickness, with much spar or other mineral matter; but the actual space is not unfrequently filled up with clay.

Obeying the law of faults already spoken of in reference to the coal measures, there are certain technical rules for miners in slip veins, derived from observation, and extremely useful. Amongst these may be mentioned the fact, that if the vein traverses several strata, it will be found most regular in the thickest of them. It is also the case that the ore in such veins is extremely irregular, following no law that can be traced to have regard to the nature, magnitude, regularity, extent, or other conditions of the vein.

It is regarded as a bad sign in a working to find the vein diverge into strings; and, on the other hand, a junction of two or more strings or veins is looked on as favourable. Veins that cross the prevailing systems have rarely been found so productive of metallic ores as the others, except at the place of crossing, where they are usually rich.

Besides the more regular rake veins, as above described, there are some of the same general kind, which are, to a certain extent, exceptional. The most remarkable are those which open suddenly into large bellies of ore, and those which open and close alternately, forming waving veins. In these cases there is little if anything to guide even the most experienced miner; but it often happens that such veins are of great value where they open, although, when once closed, it is quite uncertain whether they again contain ore.

Pipe Veins are of the nature of irregular cavities, inclined at various angles to the horizon, and consisting generally of expansions, or hollow spaces, parallel to the bedding of the rocks in which they occur. They differ therefore essentially and in principle from the crevices which form rake veins, though in some districts they are quite as remarkable for their mineral wealth. Such veins are occasionally filled with spar and ore, and sometimes almost entirely occupied with soft mineral soils. They are by no means confined to a tubular form, nor are they always continuous between two distinct beds of stone; but they owe their name to one peculiar characteristic—namely, that they have no proper longitudinal bearing, and can only be regarded as having the direction of their length; and this, as has been said, corresponds to the dip of the strata in which they occur.

Flat Veins, like the former class, correspond with the strata, but instead of being irregular cavities, are, as the name imports, comparatively flat, or at least correspond irregularly with the stratification. The beds above and below such flats are usually distinct and well marked, and so far they resemble beds of coal between shale and sandstone, but they contain spar and ore. Occasionally several flat veins extend between bands of rock from the place where a rake vein crosses, while sometimes an accumulated vein occurs of the nature of a pipe, connected with flats of ore and lead, to form a rake vein. Some cavities thus filled are of extraordinary dimensions.

The kinds of veins above described are chiefly found in the limestones and shales belonging to the carboniferous series of rocks, and form a well marked and important group, especially for lead and zinc ore (sulphurets) in this country. Something of the same condition prevails on the continent, especially in the limestone districts; but the veins (called *lodes*) in Cornwall, and many other mining districts, are so far different, in important respects, as to need special description.

Direction of Lodes.—When metamorphic rocks (including under this general name all granites and other rocks commonly spoken of as igneous) are carefully examined, they are always found striped and variegated by a multitude of threads or irregular veins intersecting the mass. Many, indeed most of these, are of some simple mineral, either quartz, limestone, sulphate of baryta, or others, varying according to the nature of the rock; and in such case, the directions of the veins are not such as to give any idea of system. Besides these, however, there are other veins often much larger in dimensions, though of the same nature, partially filled with ores of various metals, and not unfrequently so far capable of being grouped into systems as to enable us to speak of a definite compass-bearing as belonging to a certain series or group of veins. It is also found that the mineral veins containing ore are more or less parallel to the general line of elevation which has brought up the mountain range or elevated bands of metamorphic (igneous) rock in the district. Thus in Cornwall, a glance at the geological map would show at once that this direction was east and west, or nearly so; and this accordingly is the bearing of the principal rich metalliferous veins of the district. There are, however, other not unimportant veins at right angles to these, usually bearing metals different from the former and less abundant, and sometimes there are veins running nearly north-east and south-west, which are called *contras* (technically *counters*). These are the three kinds of mineral vein or lode of the south-west of England, the right running, or east and west lodes, containing copper and tin (the metals of the district); the cross courses, or north and south lodes, usually bearing lead; and the contras north-east and south-west, or north-west, and south-east, not often valuable, but bearing copper rather than lead.

Thus in the lead veins already alluded to there are certain rules that appear calculated to guide the miner, though the reason has not yet been clearly made out. Thus changes of all kinds in the nature and even in the hardness of a rock are indicative of a change in the yield of ore: an entire change of ground is rarely without a marked alteration; and in respect of particular metals, a change from slate to granite is favourable for tin, but unfavourable for copper.

Magnitude of Lodes.—The magnitude of true veins or lodes is exceedingly various; workable veins existing in which the thickness of the metalliferous portion is only a few tenths of an inch, while others range for many hundred fathoms, and even for miles, always rich and valuable. Sometimes when a vein expands it becomes poor; but instances are known where the thickest part of a rich lode is also the richest part. There are masses of iron ore in Piedmont three hundred and fifty yards thick; and the great open mine at Fahlun, in Sweden, is half a mile long, and several hundred yards wide. Such masses are sometimes called stockworks, from a German word.

The depth of the metalliferous portion of a lode is unknown. It is, however, generally imagined, perhaps without much reason, that the ores of tin are most valuable at a small depth, while those of copper increase in value and amount as we descend. The swelling out, as well as the bifurcation of a vein, certainly affects its richness. The transition from shales or schists (called *killas* in Cornwall), to granite or elvan (porphyritic dykes so called), is sometimes accompanied by a great improvement in a lode crossing them; but this sometimes impoverishes it.

Lodes range along the surface sometimes for a long distance, being rich at intervals; and the distance has some reference to the magnitude of the disturbing forces affecting the district. Thus, while there are few instances in England of lodes being distinctly traceable many miles, there is a vein in Chili nine feet thick, which has been proved

for ninety miles, and which is accompanied by branches thirty miles in length. The width of this lode is about nine feet.

The nature of the rock enclosing the lode has already been spoken of as often greatly affecting the form of the vein, its magnitude, and its riches. The presence of dykes of igneous matter (elvans), is also to be noticed as influential. There is no limit to the varieties of appearance presented by veins in different districts, and nothing short of sound knowledge and large experience will justify any one, however acute, or however familiar with the details of any one district, in coming to a conclusion as to the value of mineral indications in a new locality.

Filling of Veins.—Mineral veins are not merely crevices in rocks, but crevices occupied with mineral substances in a certain condition; and we must now consider this condition in reference to the metalliferous ores. By far the greater part of the contents of a vein or lode consists of earthy minerals, which, however, are generally in a state more or less crystalline. The name of spar is given to such crystalline minerals, and amongst them appear quartz in various states; carbonate of lime, also in various forms, fluate of lime, sulphate of lime (comparatively rare), sulphate of barytes, &c., besides many beautiful and more complex minerals. With them are associated, often in great abundance, iron pyrites or sulphuret of iron; and as metalliferous ores we find occasionally several native metals, metallic oxides, metallic sulphurets, and numerous double and triple salts of metals, besides various combinations of metals. The object of the miner is to extract such of these ores as will repay the cost of getting and working. In place of the hard crystalline or semi-crystalline earthy minerals are sometimes found soft clayey substances, often coloured with iron; and not unfrequently, when the vein is in a large fissure, it is occupied with a large quantity of tough clay, greatly interfering with the value of the lode, which, under such circumstances, usually dies out. Such a vein is called, by Cornish miners, a *flookan*.

There is often ample proof in the mode of filling a vein that this operation has taken place subsequently to its formation, and in many cases something of the history can be traced. In mines in Germany it is not uncommon to meet with veins chiefly occupied with a breccia or conglomerate, cemented together by quartz, carbonate of lime, or other mineral. Remarkable instances of this are described by Werner, and in many of these instances there is a large open cavity connected with, and forming part of, the vein; and there has evidently been in such cases a considerable amount of mechanical arrangement, succeeded by chemical action on a large scale.

Intersecting Veins.—Sets of veins exist in all mining districts which are crossed and displaced more or less by other veins. The latter must evidently be of more modern date than the former, and thus something is learnt as to the history of the filling up. Since, however, veins are found containing all the usual earthy minerals, and most of the common metals penetrating rocks of the most recent date (and therefore clearly themselves yet more modern), there ceases to be any question as to the possibility of these repositories being formed and filled up within a very brief period, compared with that occupied by the deposition of known strata.

Distribution of Metals.—Rocks of almost all kinds are occasionally split and fissured, either by simple contraction or upheaval, so that veins of some sort or other are widely spread in all countries. It is even the case that certain metals are almost equally distributed, such as iron and manganese; but the veins are seldom worked, for various reasons. Practically, however, it happens that the valuable metals and metallic ores are either dispersed at rare intervals over the earth, being confined to a

few localities, distant from each other, or else that they are usually present in quantities so small as to have no value. Thus, while gold, as already said, is very universally met with, it seldom pays the cost of working; and silver, though much less common, is more profitable for regular mining. Copper, lead, tin, and zinc, the metals of which, next to iron, there is the largest and most regular demand, involve far less risk, and, in the end, produce much larger profits. Mineral veins, therefore, are objects of the greatest interest in all their details, and any information concerning them is useful, and may lead to important results. The associations of metals with each other, and with various veinstones or spars—the relative value of veins having certain common peculiarities of position or appearance—the appearances at the surface, which lead to a knowledge of the interior, are all points of interest; and, having said a few words with regard to some of them, we may proceed to give the student a practical definition, which will guide him in many cases, and be a starting-point for further information in many others.

Recapitulation.—Mineral veins, then, are of the nature of fissures or crevices, more or less nearly vertical, produced in rocks, generally metamorphic, and often originating either in simple contraction or contraction followed by upheaval. They are, of course, newer than the rocks which they traverse, and they cross all the rocks in their way, though the result differs much in different cases, according to the nature and mechanical condition of the rocks.

Formed in this way they are found to obey certain laws. They have usually what are called *cheeks* or *walls*—definite partings, often somewhat different from the containing rock, and more or less parallel to each other. They exist in sets of several in the same district, approximately parallel, and others at right angles, with a few that are intermediate; but they are connected by branches, strings, or threads, which are, in fact, smaller veins not following the law of direction. They vary exceedingly in all dimensions, length, breadth, and depth; they rarely terminate abruptly, and those of one set are sometimes crossed by those of another of more recent date.

These veins are also filled with mineral substances, most or all of which have been gradually introduced since their formation. Many of them have been deposited from water; others, in all probability, from hot vapour and steam. In others again (probably a small number), there appears to have been injection of mineral matter in a melted state: while, in all probability, the whole number have undergone great subsequent change, and may have been entirely filled in consequence of a segregation of particles from the mass of the containing rocks, and from the contents of the vein, so as to produce these complicated crystallizations and varied mineral and metallic substances often met with.

In addition to this, and as further illustrating the subject, it may be added that productive veins are found, in most cases, to contain a larger proportion of metalliferous substances near cross courses, close to and at the point where a vein enters a different rock from that which it has hitherto traversed, and near the points where strings and threads (hence called *leaders* and *feeders*) come in. On the other hand, a sudden enlargement of a lode is often a sign of poverty. The divergence of a lode into a number of small ones is also unfavourable; and a great mixture of minerals is not generally likely to lead to an abundant supply of any one.

Gossans.—With almost all lodes in certain districts, and with certain classes of veins generally, there is so large a quantity of iron present that the decomposition of this metal near the surface produces a ferruginous stain. The tops of many lodes

(near the surface) are also not unfrequently open, cavernous, and formed to a considerable extent of iron oxide. Thus in Cornwall, and many parts of Germany and France, in mineral districts, an irony appearance of a vein, where seen at the crop, is regarded as favourable. In Cornwall such an appearance is called a *gossan*, and a Cornish miner is apt to believe that a good gossan necessarily leads to a good vein in the depth; and, on the other hand, that no large vein is worth anything without this accompaniment. The *chapeau en fer* in France, and the *Eisenkopf* of the German miner, are similarly valued; but it is quite a mistake to assume the universality of this law. In some rich mining districts no iron, or scarcely any, exists in the earth, and therefore the ferruginous stain is altogether wanting, although the richest and most valuable ores of copper, tin, and lead, may be underneath. The gossan is a good indication where a country is well known, and experience has proved that it ought to exist; but in a new district other appearances must decide as to the value of a property. In Cornwall it is especially common, and often extends to as much as thirty fathoms below the surface. In itself, consisting of iron oxide, it is valueless, but it has been found in many cases to contain a small quantity of gold (a few pennyweights to the ton). The Poltimore mine (North Devon) has become celebrated within the last two or three years as containing more than usual of this valuable metal; but on operating on large quantities it has not appeared to be sufficient to pay the expenses.

Aqueous Theory of Mineral Veins.—The opinions of writers and practical men, as to the cause of mineral veins and the mode of their filling up with metalliferous ores, were extremely vague and unsatisfactory before the time of Werner. That eminent geologist, trusting to the local knowledge which he possessed, and neglecting, in his broad and able generalizations, the doubtful and obscure accounts which appeared to contradict his own researches, was led to propound a theory of veins which now is quite untenable, although it was sufficiently important, and embraced a sufficient variety of facts, to be well worth notice at the time.

Werner asserted, that true veins were of necessity rents or crevices open in their upper part, and filled up from above; that the matter they contain was precipitated from solution or suspense in water, just as beds or strata are formed; that they are of different ages, distinguishable by the order of deposit of the contents; that they are limited in range and position, and grouped into certain districts. These assertions are no doubt true for certain cases, and especially for some of those which the great Saxon geologist had himself examined; but it is equally certain that they are altogether incorrect with regard to the majority of cases. Many veins, containing carbonates of lime, iron, copper, &c., oxides of iron, and numerous other minerals, may doubtless have been enlarged and filled by the agency of water.

Theory of Sublimation.—In contradistinction to this view, another theory was propounded some years ago by M. Necker, based on the fact that mineral veins almost invariably occur in mountain districts, and are more or less immediately connected with disturbances of strata, and with great lines of dislocation, or else are in the immediate vicinity of igneous rocks. Monsieur Necker, struck by these facts, which are very evident in a large number of cases, has investigated the subject with reference to these three questions,* viz.—first, whether there is any unstratified rock near each of the known metalliferous deposits?—secondly, whether, if none such appear at the surface, there is any distinct evidence or any high degree of probability that an unstratified rock exists immediately under a metalliferous district, and at no great distance

* "Proceedings of Geol. Soc.," vol i., p. 392.

from the surface?—and, thirdly, whether there are found any metalliferous deposits entirely unconnected with igneous rocks?

The first of these questions may certainly be answered in the affirmative, by reference to a vast number of cases, forming the great majority, of known mineral veins in all parts of the world. The great mining districts, in all countries, have been shown to be immediately connected with unstratified and crystalline rocks.

In answer to the second question, M. Necker refers to a number of instances in Europe where mineral veins occur nearly and evidently associated with unstratified rocks, though not actually proceeding from or passing into them.

Such is the case, for instance, in the Isle of Elba, where an abundant supply of iron ore is obtained from veins in sedimentary rocks; but the close vicinity of erupted porphyries and other igneous rocks, and their actual appearance at the surface not far from the veins themselves, is sufficient proof of their presence in considerable abundance.

With regard to the third question, the answer is, although not absolutely in the negative, yet sufficiently so to add great strength to any argument that might be deduced from the answers to the former questions.

The quicksilver mines of Idria in Carinthia, and the lead veins in the mountain limestone of Flintshire and the south-west of England, are among these apparent exceptions; but the former occur in a district nearly connected with the great elevations of the chain of the Alps in its continuation eastwards, and the latter are not far from considerable dislocations and disruptions of the carboniferous strata.

Observing how commonly it happens that mineral veins make their appearance in districts characterised by the presence of altered or metamorphic rocks, it might naturally be assumed that they were chiefly confined to strata of ancient date. This appears, however, to be by no means the case, and metallic ores are known to occur in rocks of the secondary and even tertiary periods. And although the generalizations attempted to be deduced by early geologists, as to the age of metals, are not altogether borne out by facts, there still seems to be a certain order of antiquity in their arrangement; for tin has not hitherto been met with in any rocks of modern date; nor have the precious metals been obtained except from the older veins.

Apart from considerations of age, there are other circumstances, dependent apparently upon local influence in the distribution of metals, which are also worthy of notice. The slates, for instance, of Cornwall and Devonshire are of nearly the same geological age as those of North Wales and Cumberland; but the metalliferous ores found in them differ exceedingly—tin abounding chiefly in the southern counties, copper being the staple in the central and some parts of the northern, and lead in other parts of the northern district. It is true, indeed, that copper and even lead are found with tin in Cornwall, and that lead is associated with the copper of North Wales and Coniston Water Head; but there are indications of preference, if we may so say, which well deserve careful investigation.

It is a fact of considerable interest, that the limits of mining districts are often very decided, and marked by peculiarities in the physical features of the country. In the north of England, the neighbourhood of Cross Fell has been worked with the greatest enterprise; but no instance has occurred (it is stated by Professor Phillips) of a single vein being traced across the great Penine fault to the west. Similar facts have been observed with regard to the Flintshire veins, which occur in the carboniferous limestone, and which in no instance enter the silurian rocks. In this latter case, as in

many others, the older rocks rise on the line of a great axis of disturbance, and seem entirely to cut off the whole of the mining ground.

M. Necker considers it a necessary result of the connection he has successfully endeavoured to show between veins and igneous rocks, that the method of *sublimation* was the one adopted by nature in almost every case to fill up those cracks and fissures in the crust of the earth which have resulted in mineral veins.

Igneous Theory.—This theory of sublimation differs considerably from that of igneous injection proposed by Hutton, and both of them are diametrically opposed to the theory of aqueous deposition as promulgated by Werner.

The Huttonian hypothesis, that the contents of veins were in all cases injected from below in a state of igneous fusion, is scarcely more probable or better founded than the rival theory of the Saxon geologist.

That some, indeed, of the cracks in strata, such as trap dykes, have been so injected, must be regarded as probable, because in many cases we actually see the effects of heat on the rocks forming the walls of the dyke; and it is clear that quartz and many other minerals, and probably occasionally metalliferous ores, may have been forced up from below. But if this theory were really true, we should surely sometimes find the ores, as we do the basalt, protruding above the surface, and we could trace the direction of the currents in which the matter flowed, and discover some relation between the different masses of ore that occur in the veins.

With regard to the theory of sublimation, by which it is meant that the minerals and metallic ores have been volatilized by heat, and afterwards assumed their place by condensation, there can be no doubt of its being occasionally a *vera causa;* but, like the other theories, it fails in universal application. Both this and the Huttonian theory of injection would seem to require that veins should be richer in metallic produce as we descend to greater depths in a mine; but it has been already remarked, that experience is opposed to the existence of any such necessity.

Electrical Theory.—An attempt has been made to account for the phenomena of mineral veins by the agency of electricity; and the advocates of this hypothesis consider, that by referring to electro-chemical action, many of the most characteristic and remarkable of the facts that have been observed may be satisfactorily explained. The great improvements and discoveries that have of late years been effected in this branch of science, and the certainty that electricity is a most powerful force, acting incessantly, and affecting even the minute structure of inorganic bodies, corresponding almost with the vital principle in its power of removing, re-arranging, and selecting the particles of dead matter, render every suggestion, with reference to this force, worthy of the most careful attention.

The experimenter to whom science is chiefly indebted for the original researches on which the electrical theory of mineral veins is founded, is Mr. Robert Were Fox, who greatly distinguished himself by a vast number of investigations on the mutual relations of electricity and magnetism, and their mode of action in re-arranging the particles which compose the crust of the globe.

Assuming the existence of fissures produced in the solid substance of the earth's crust at various times, and taking it for granted also that they penetrate to great depths, are exposed to a high temperature, and must have been filled up progressively, Mr. Fox has shown the probability there is of heated water having been circulated in them by ascent and descent, and the certainty that quartz and earthy substances might be deposited from water in that state. He then proceeds to explain, that in such fissures,

filled with metallic and earthy solutions, the different sorts of matter on the sides must necessarily produce electrical action, which might be rendered more active by the unequal temperature of the water and the walls of the fissure. Currents of electricity thus generated would pass more easily in the fissures than through the rocks, and they would pass in directions conformable to the general magnetic currents of the district, and therefore east and west, or somewhat to the north or south of these points, according to the position of the magnetic poles at the period when the process was going on.

Electrical currents thus circumstanced would deposit the bases of the decomposed earthy and metallic salts on different parts of the rocky boundary of the vein, according to the momentary electrical state and intensity of the different points; and the nature and position of the rocks would be influential in determining these conditions. When by such processes particular arrangements had happened, new actions might arise, and amongst them a series of secondary phenomena, such as the transformation of ores without change of form—a fact otherwise very difficult to comprehend. Lateral rents might also be filled by virtue of these new actions, even though they were not in the most favourable lines of electrical circulation.

In confirmation of his views, Mr. Fox has actually succeeded, by direct experiment, in forming well-defined metalliferous veins by means of voltaic currents operating under circumstances resembling those supposed to have occurred, and which sometimes do occur in Cornwall.

Absence of any Universal Method.—Before bringing this subject to a conclusion, it may be observed, as some, and perhaps a sufficient, excuse for the uncertainty of our knowledge concerning it, that it is the most difficult of all departments of geology; for it requires the closest investigation, combined with the broadest general views, while the means of pursuing such investigations are scanty and unsatisfactory, and the examination of mineral veins in the mines themselves is rarely productive of any useful result. It cannot, therefore, be a matter of surprise that different, and even opposite, views have been advocated by those who have only partially observed Nature; and perhaps it is the safest plan, as it certainly seems the only way by which we can reconcile conflicting opinions, to take a middle course, and admit the validity of each cause that has been assigned.

Nor is such a mode of escaping from the difficulties of the case unreasonable or inconsistent with what we know of the ordinary course of Nature, in which all means are used, and every variety of cause employed, to bring to perfection one great result. In examining the contents of veins, one cannot but be struck, not only by the appearance of a complication of causes, but by the evidence of their succession, rendering it probable not only that different agents have been employed, but that they have done their work separately as well as conjointly; that they have operated at different periods; and that one has produced effects for which another was inadequate.

Discovery of Mineral Veins.—Reverting to the main facts connected with these phenomena, the student will remember that metalliferous veins, or lodes, are limited in geographical and geological distribution; that they exist in sets, having different compass-bearings; that they generally intersect the surface; and that they often cross or run into each other. They are found either accidentally or by actual search; in the former case being exposed in river-beds, or sea-cliffs, in road-cuttings, and by ordinary agricultural occupations. They are sought for by observing natural indications in a known district, by tracing the gravel of a stream by a process called *shoding;* by opening the surface by what are called *costeanings*, or costeaning pits; and, lastly, by

sinking shafts, or driving adits into a hill-side to cut the lode, and if worth while removing the ore. We do not include among methods those peculiar powers assumed by some persons, even at the present day, who believe in the divining-rod, and fancy they see a lambent flame floating over productive lodes; although it would not be right to omit all notice of so peculiar a superstition which still prevails in some districts of Cornwall.*

Of the natural indications of copper lodes, the water of the neighbourhood is one by no means unimportant. The harsh taste of the water is, of itself, a guide; but a better expedient is to immerse a piece of bright iron in it for two or three days, when the colour will decide, as the copper (if any exists) will be deposited on the iron, communicating a decided cupreous tint.

Costeaning is a method commonly adopted to discover the presence of a productive mineral vein. The word literally means "fallen tin," and the process consists of sinking small pits through the surface deposits to the solid rock, and driving from one to another across the direction of the vein, so as necessarily to cross all the veins between two such pits. Where the prevalent strike of the principal systems of right-running veins is clearly made out in a district, costeaning is likely to be found a very effectual process, and may safely be adopted for any metal. The pits are often sunk several feet into the rock before the communications are made between them.

The method of costeaning, already referred to, is sometimes modified by working drifts for discovery across the direction of the right-running veins of a district. Where the rock is not very hard, and is not covered up at the surface by detritus, or a thick coating of vegetable soil, open cuttings may be made in this way at a very small cost; which will lay bare the lodes for a long distance. If, in consequence of the form of the ground, this can be done at a depth of twenty, thirty, or forty fathoms, without getting below the water level, and where driving is not expensive, either from the nature of the ground or the timber required to support it, the lodes will be much more effectually laid bare. Cross courses are not unfrequently made use of in this way; but it must be borne in mind that the condition of the lode where crossed is often, in such case, very different from that elsewhere shown.

Shoding is another ancient, but useful, mode of determining the position of a lode. Like costeaning, it was originally adopted in Cornwall for tin stones, but has since been introduced as part of a general system of discovery in other cases. The principle in-

* It is singular that the divining-rod should have so far entered into the list of methods for discovering ore in Cornwall as to occupy in its description several folio pages in the otherwise sensible and useful treatise by Mr. W. Pryce, well known to all persons interested in the literature of mines. This book bears date 1778; and in concluding his account of the "Virgula Divinatoria," as it is there designated, the author gives a number of illustrations of its successful use in Cornwall. He then says, "Hence it is very obvious how useful the rod may be for the discovery of lodes in the hands of an adept in that science; but it is remarkable that, although it inclines to all metals, in the hands of unskilful persons, and to some more quick and lively than to others, yet it has been found to dip equally to a poor lode and to a rich one. I know that a grain of metal attracts the virgula as strongly as a pound; nor is this any disadvantage in its use in mining; for if it discovered only rich mines, or the richer parts of a mine, the great prizes in the mining lottery would be soon drawn, and future adventurers would be discouraged from trying their fortune." It is singular to find such opinions prevail; but the history of the period abounds with similar instances, and the divining-rod is only one of a large class of deceptions where success would seem to depend only on unblushing impudence, or the grossest self-delusion on one hand, and the most wilful blindness on the other. That honest, trustworthy, and even intelligent people have given way to the delusion is, however, beyond question.

volved is, that when a part of a lode consisting of fragments of heavy ore mixed with the comparatively light spars, and stones accompanying it, is broken off from the top of the lode during a general denudation of the surface, the lighter particles will be carried farthest, and the heavier left behind; so that, in fact, there will be a natural grouping in the order of the specific gravity of the stones. Thus the largest quantity of ore, and the largest fragments, will be left nearest the vein, and the others will be conveyed along the river course, gradually diminishing in amount. It will also happen that the ore, being derived from a small breadth of vein, is comprised within narrow limits at the top of a hill, but may cover a large space, and be distributed by several streams in the plains below. It has already been remarked that tin shodes are the most common, owing to the high specific gravity of the ore. Shodes of mundic (iron pyrites), copper pyrites, and lead ore, are also found, but less abundantly. Quicksilver shodes, and those of wolfram (a valueless mineral, resembling tin stone), are often met with. Silver and gold shodes are known; but the metal in the latter case is more usually obtained from the shode than the vein; and in the former is not so effectual, owing to the lightness of many silver ores. The following account of the method, taken from Pryce (already quoted) will give the best idea of the process still adopted:—

"When the miners find a good stone of ore, or shode, in the side or bottom of a hill, they first of all observe the situation of the neighbouring ground, and consider whence the deluge could most probably roll that stone down from the hill; and, at the same time, they form a supposition on what point of the compass the lode takes its course: for if the shode be tin or copper ore, or promising for either, they conclude that the lode runs nearly east and west; but if it is a shode of lead ore, they have equal reason to conclude that the vein goes north and south. After finding the first stone, or shode, they sink little pits as low as the first rubble, which is the rubble or clay never moved since the flood, to find more such stones; and if they meet with them, they go further up the hill in the same line, or a little obliquely perhaps, and sink more pits still, while they find shode stones in them; but they seldom sink those pits deeper than the rubble upon the shelf, except they are near the lode. If the shode is found in vegetable soil, the lode is not at hand; but if it lies deep, massy, and angular, it is a certain sign that the lode is not far off; more especially if the shodes are of a pyramidal or conical form, and the base or heaviest part of them lies pointing one way, it is both a sign that the lode is not far off, and that it is to be found opposite to the base, or heaviest part of the stones.

"As they advance thus nearer the lode with their pits, they find their shode more plentiful and deeper in the ground; but if they chance to go further from the lode, or pass the yonder side of it, there is a greater scarcity of the shode, or, perhaps, none at all: in which case they return to their last pit which produced shode most plentifully, and work the intermediate ground with more care and circumspection, by drifts from one pit to the next, until they cut the lode. Sometimes they find two different shodes in the same pit at different depths; then they are sure that there is another lode further over; and, in training up to the second, they may meet with the shode of a third. However, when they are just come to the vein they set out for, they find an uncommon quantity of shode stones answering to the description before given, and then they say that they have the *bryle* of the lode; upon which they dig down into the solid hard rock, which has never moved or loosened, until they open the lode, and find its breadth by the walls in which it is enclosed."*

Many lodes, however, yield no shode; the upper part of the lode either containing

* See Mineralogia Cornubiensis, p. 127.

no ore, or the detritus having been carried too far, and being ground into too small a state of division to be recognisable. In these cases there is little to guide the miner beyond the nature of the gossan, or other appearances at the back of the lode, both of which are liable to deception. After all, it must happen in such cases that the discovery, if made, will be due to accident rather than to the intelligence of the discoverer.

Mining Operations.—Having explained these preliminary processes, we may proceed now to the actual operations of mining: and since, in England, the county of Cornwall, and that part of Devonshire immediately adjacent, are the districts in which mining operations are conducted on the largest scale, and with reference to the greatest variety of mechanical appliances, we may conveniently take them as the type of copper and tin mining. Lead mining and dressing, when on the largest scale, are conducted somewhat differently, and in other districts. They need but little separate description.

The object here being chiefly to illustrate the condition of mining in a practical way, it will be best to do so in reference to the miner's duties, and the different circumstances which more or less affect his lot and fortunes. We may premise that the term "miner" exclusively applies to those actually working in the mines—the capitalists, or those employing the miner, being known as the adventurers. Each mine is owned by a company of adventurers—the capital being divided into shares, which are marketable and transferable, like those of a railway company, and in Cornwall being subject to special laws, and a method of limited partnership called the cost-book system.

Lord's Dues.—To explain the process of mining, it is advisable to begin with the beginning; in other words, to follow a mine from its first establishment, until it is in complete and active operation. When there is reason to believe that a lode worth trying exists in a place not hitherto worked, a set of adventurers form themselves into a company for the purpose of working it. In doing so, their first business is to apply to the lord of the soil for a license to work the lode for a given time—sometimes for six months, but generally a year—upon trial; the lord to receive a specified proportion; usually from one-tenth to one-fifteenth of the ore which may be raised during the period of the license. The lord also comes under an obligation, should the adventurers, at the expiration of the license, be disposed to continue the working of the mine, to lease it to them for a certain number of years, generally upon the same terms as those of the license, so far as his share of the proceeds is concerned. Should the project prove a failure, it may be abandoned at any time before the expiration of the license. This mode of paying the lord his dues is objected to by many, on the ground that it frequently operates harshly upon the adventurers. They urge, that however much the mine may be losing, the lord is always sure of a profit. Thus, if £15,000 worth of ore is raised and disposed of, it may cost the adventurers £15,000 to raise it. If, in that case, they paid the lord his fifteenth, the company would lose £1,000 instead of making a profit. But this would be equally the case were the lord, instead of his share of the proceeds of the mine, to receive a fixed money rent from the adventurers. Thus, if the fixed rent was £2,000, and the produce worth £15,000, as in the case supposed, the loss to the adventurers would be £2,000, instead of £1,000. It is quite true, that by the present arrangement, the lord is always sure of a profit, because he runs no risk; but that profit, like the profit of the adventurers, fluctuates with the price of copper, and when the price is low, the present system of rent-paying bears upon them more lightly than any other arrangement would do.

The course here mentioned is that which is pursued when it is in contemplation

to open up an entirely new mine. But it frequently happens that a new mine is opened within bounds already set out to a company of adventurers, and within which they are already working a mine. In such case no new license is, of course, required. When a new mine is thus opened, the way is generally led by a party of miners, who undertake to try on the "tribute system," which will be immediately explained, either what they believe to be a fresh lode, or a portion of the lode already worked, but which the existing operations are not likely to reach. In the latter case, the result, if the experiment prove successful, is generally the sinking of some new shafts, which are soon connected with the existing works, whereby the scope of the existing mine is only enlarged. But whether an entirely new mine is to be opened, or the range of an existing mine is only to be enlarged, the operations commence by the sinking of shafts, and the construction of levels; these must be done ere the mine is in workable condition; and this brings us at once in contact with the actual work of the miner.

The miners are divided into two great classes—the surface and the underground men. The latter are by far the most numerous, being fully three to one, as compared with the former. The underground men are again divided into two separate classes, known, in mining phraseology, as the "tutmen," and "tributers."

Tut-work.—The tutmen are those who do "tut" work, which is neither more nor less than simple excavation. In commencing a mine, therefore, the tutmen are the first called into requisition. They sink the shaft and run the levels—all the ore which may chance to be raised during the process belonging exclusively to the adventurers, always with the exception of the lord's dues. The work is given out by the fathom; it is regularly bid for, and the parties offering to do it for the lowest price secure the work. It generally happens, however, that one of the captains of the mine ascertains beforehand, as far as can be, the nature of the work, and sets his own price upon it—the price at which it is taken seldom varying much from the captain's price. Both tut and tribute work are usually taken by what is called a "party;" the party, in both cases, consisting of several individuals, their number varying according to circumstances. The party is divided into gangs, which relieve each other in rotation. There are three gangs to a tut party, each gang working eight hours at a time—the whole twenty-four hours being thus turned to account. The gangs employed in tut work are strictly required to relieve each other at the proper time. As their work is chiefly preliminary to the real business of mining, it is, of course, the object of those who employ them to have it done as speedily as possible. Nor are the interests of the tutmen themselves interfered with by this—for, as their work is piece-work, the sooner they get through it the better. A greater degree of discretion is generally given to the tributers, as to how long they may work, and when they may relieve each other—it being supposed that they have sufficient inducement to diligence in the share which they have in the proceeds of their own operations. At the poorer mines, tutwork is generally confined to ground which is not metallic—tribute work having reference invariably to metallic ground. At times, however, tutwork embraces ground which is metallic, but this is always in the richer mines. When the ore is known to be good, it is raised at so much per fathom, in which case it all belongs to the adventurers. It is generally work of a more speculative kind that is set on the tribute system; and it is because in the poorer mines all the work is of this kind, that the whole of the ore is raised on that system. But even when it is raised on the other system—that is to say, by tutwork—it is not unusual to give the men employed a small interest

in the ore produced. This is done in order to make it their interest not to waste or spoil the ore.

The work of the tutman is, as already said, that of simple excavation, at so much per fathom. He bids for it with a real or presumed knowledge of the nature of the ground to be worked—the same knowledge being possessed, or presumed to be possessed, by the captain assigning him the work. Miscalculations in this respect are not unfrequently made, which are, in their results, sometimes in favour of, and at others against, the tutman. Although their work has not so much the character of a gambling transaction about it as has that of the tributers, still it is not entirely free from that objection. He may bid for work, and it may be assigned to him, on the supposition that the ground is hard and difficult to be operated upon—or the same may be done on the contrary supposition. In the one case it may be found, after a little trial, much easier, and in the other much more difficult, to work than was anticipated. Hence, by the chance of his work, he may be a gainer to some extent, or a severe sufferer. Thus, after taking work which appears easy, at a comparatively low price per fathom, he may, after penetrating for some distance through disintegrated granite, which is easily removed, or soft clay, come to a hard mass of granite, which opposes a serious obstacle to his progress. This the tutman calls a "pebble," and it is a serious question with the party on discovering it, whether they will change their course to avoid it, if possible, or dash right through it, in the hope that it does not extend to any great depth. There is risk in either case, as the time lost, and the expense incurred, in attempting to turn or avoid it, may be much greater than was anticipated. Nor is it always that it can be avoided at any cost. Then, again, if they attempt to go through it, their hopes may be disappointed, as its depth may be very great. Sometimes, after going through it for some distance, they give it up in despair, and attempt to turn it, which they find, to their mortification, after having lost so much labour, that they can rarely do. When the work goes thus against the tutman, he very soon complains, and if his complaint is well grounded, a favourable modification is generally effected in the arrangement between him and his employers.

The undertaking of the tutman is to bring to the surface so much matter, whether ore or "stuff," or both together, at so much per fathom. To fulfil it, he requires the use of machinery to raise the matter excavated to the surface. That which he thus employs is, of course, the machinery on the spot, adapted for the purpose and appertaining to the mine. For this he is usually charged at a certain rate per fathom, which is so much to be deducted from his earnings. There are other deductions also to be made; but as these are common to both tributers and tutmen, their explanation will be deferred for the present. The first work with which the tutman grapples is, of course, the sinking of the shaft. The object is, if possible, to have the shaft perpendicular. Such a shaft is not only the most convenient, but it is also attended with the least expense in the future working of the mine. But much, in this respect, depends upon what is called the "underlie" of the lode. It is very seldom that the lode is perpendicular; its inclination being, as it proceeds downwards, generally to the north. If the underlie is not great, the shaft may, to a considerable distance, follow the lode. If it is great, the shaft descends, not in one continuous line, but, as it were, by a succession of steps. It will be sunk perpendicularly by several fathoms at a time, the lode all the time diverging from it to the northward. At certain distances halts are made, and horizontal courses run in the direction of the lode until it is again struck. Each time the lode is struck the shaft is sunk again, the lode to be reached again by a horizontal

course as before. As the shaft is being sunk, the levels are being constructed. It is necessary that the reader should comprehend what these are, as on his doing so will greatly depend his comprehension of the operations which follow. To enable him the more readily to understand the internal arrangements of the mine, let us suppose both the lode and the shaft to be perpendicular.

Drifts and Winzes.—The lode, be it remembered, is neither more nor less than a crevice or fissure in the granite, or in the slate, or at the junction of the two, varying in width, and generally running from east to west. This crevice is usually filled with disintegrated granite, clay, or other soft matter, interspersed with which is the metal. Were the lode perpendicular, the shaft, in following it downwards, would be perpendicular also. The shaft is usually in the form of a parallelogram, about five or six feet wide, and about double that in length. The sides are almost invariably secured with woodwork, so as to prevent them falling in. Down the middle, and dividing the parallelogram, as it were, into two squares, runs a strong wooden partition, which, in reality, makes two shafts of it. One is for the raising of the ore and rubbish; the other is that by which the miners have access to and egress from the mine. The levels are parallel courses which diverge on either side from the shaft, and follow horizontally the course of the lode. These courses are at different distances from each other; but, generally speaking, they are not more than ten fathoms apart. Thus, after the shaft is sunk a certain distance, the first level will be run—in other words, a horizontal passage will be cut from either side of the shaft, following the direction of the lode. The height of this passage is usually from five to six feet. It is also commonly three feet wide, so as to give room for the operations to be conducted within it. This is its width, however narrow the lode may be; nor is it frequently made any wider, unless the lode is sufficiently rich to warrant its being made so. There is no limit to the length of the passage or tunnel, but such as may be set to it by the superficial bounds of the mine. The shaft is then sunk, say for ten fathoms more, when similar levels are constructed, directly under those alluded to. This operation may be repeated so long as the mine continues sufficiently wealthy to induce the adventurers to keep sinking the shaft and constructing new levels. Some mines have attained a depth of three hundred fathoms, so that they have about thirty different sets of levels, all ranging one beneath the other. When a new level is wanted, the shaft is first sunk to the proper depth, when the level is opened up. The *rationale* of a mine, under these circumstances, would be neither more nor less than a perpendicular hole sunk in the lode, with a series of horizontal holes projecting into it, at regular distances from each other, from either side of, or at right angles to, the perpendicular one. It is obvious that, when the lode is not perpendicular, which is usually the case, and the shaft, instead of being continuous, descends, as it were, by steps, the levels, instead of being directly under each other, will be below, but a little to the side of each other—the distance to which they will be to the side of each other depending upon the inclination or underlie of the lode. Thus, if the lode underlies to the northward, each successive level will be more to the northward than those above it, and less so than those below. Generally speaking, instead of the shaft following the levels, and so being broken into different sections, it is sunk perpendicularly, being accessible to the different levels by means of horizontal curves connecting them together.

When the mine is extensive it is usual to sink several shafts. Thus, at the Carn Brea Mine, which has a superficial extent of a mile and a half in length, and about three quarters of a mile in width, there are from twenty to thirty shafts. Other mines

have even more than this. These shafts are often situated along the line of the lode, and are constructed to facilitate the operations of the mine, which would be much impeded were there but one outlet, when the levels have been pitched far back. When several shafts are thus situated, the levels extending from one will run into those extending from another, so that the different levels will thus have the advantage of more than one outlet. Several shafts are sometimes sunk when the mine is very deep, and the underlie considerable, not in the direction of the lode, but in that of the underlie, so as to perforate the body of the lode at different points. These are mainly intended to facilitate operations in the lower levels, which would otherwise be too far removed from the outlets of the mine. When the mine is deep, and the shafts are far apart, the levels are here and there connected with each other by what are called "winzes." A winze is a cutting extending from one level to another, and when perpendicular, which is not always the case, is just like the section of a shaft extending between level and level. This has the double object of facilitating the communication between the different levels, and of improving the ventilation of the mine. Sometimes, despite the presence of numerous winzes, the circulation of air is so imperfect in a mine, that boys are employed below in working machines which increase the current.

Adit Level.—The description of the internal economy of a mine would be incomplete without an allusion to what is known as the adit level. This is constructed in mines which are situated on the side of a declivity, and its chief object is to prevent the necessity of having to raise the water pumped from the mine to the very top of the shaft. The adit level may be the first, second, or third level of a mine, counting from the top, the depth at which it is run depending partly upon the depth of the valley upon which it opens, and partly upon the nature of the portion of the mine above it, as to whether it is wet or dry. Thus, if a mine is situated on the side of a valley, and the shaft is sunk about one hundred feet above the lowest level of the valley near the mine, the adit level may be run out into the valley, about ninety or a hundred feet down. Through this the water will escape, and the expense of raising it to the top will be saved. The adit level is also useful as an auxiliary to ventilation.

These observations apply equally to copper, lead, and tin mines; and everything here described is necessary to be done before the mine is in working order. And all this is exclusively the work of the tutmen. It does not necessarily follow that ore has been raised during the operations, although considerable quantities are sometimes brought to the surface in sinking the shafts and running the levels. It is not until these are completed that the real work of mining begins. The levels are then taken possession of by those whose business it is to produce the ore. When the lode is very rich, the tutmen, as already explained, are engaged to work it at so much per fathom. But the production of the ore is generally the work of the tribute man, who is, after all, the real miner.

Setting Pitches.—From the explanation here given, it will have occurred to the reader, that between every two levels on either side of the shaft a deep belt of the lode intervenes. Thus, between the surface and the first level there is such a belt, as also between the first and second levels, &c. That between the first level and the surface is seldom worked to any great extent, but the others are worked according to their richness and quality. These intervening belts are, in the language of the miners, called "pitches;" and it is by the pitch that the work is set.

Each mine has its own regular setting days; and the process of setting is as

follows :—At the proper time and place the tributers and the captains of the mine meet together. It should here be mentioned that the captains are invariably men who have risen from the rank of miners. It is their duty to set and superintend the work—to do both of which properly they must frequently descend into the mine. There are three or more of them, according to the extent of the mine, and one or more of them are invariably below. The setting is a species of auction—the captains being the auctioneers, the miners the bidders, and the pitches the subject-matter of the transaction. Since the previous setting-day more pitches may have been opened, either by the further sinking of the shafts, and the construction of additional levels, or by the extension of the levels already existing. It frequently happens, too, that pitches already partially worked, but abandoned, may be offered. In such cases they may be taken by different parties, or by the same parties at a higher rate. Both miners and captains are supposed to have a knowledge of the quality of the pitches, and it is upon this knowledge that they proceed to business. The pitches are put up, one after another, not to the highest, but to the lowest bidder. There are maps of each mine; and the pitches, levels, shafts, and winzes are all as well known to the parties concerned as are their streets to the denizens of a town. Pitch so-and-so is put up, and the bidding commences. The offer, on the part of the captains, is to set the lode to the party that will work it for the smallest share of the proceeds. This explains the position of the tributer, and the character of his work. He does not work for fixed wages, or for so much per fathom, but becomes, *quoad* the portion of the mine which he engages to work, a partner, as it were, in its profits and losses. The share, in consideration of which he will work a pitch, depends upon his belief as to the quality of the lode at that particular point. Thus, he will offer to work a rich pitch for five shillings in the pound; that is to say, for five shillings out of every pound's worth of ore which he may raise to the surface. This is called his tribute. To work a poor pitch, however, which yields but little ore to a great deal of labour, he may ask as high as thirteen shillings in the pound. Sometimes he will work at a lower rate than five shillings; but when the ore is so rich as to tempt him to go much lower than that, the adventurers generally give it out on tut by the fathom, retaining all the produce to themselves. Between four shillings and thirteen shillings in the pound is the range at which the tribute man generally works. It is seldom that there is any indiscriminate bidding, or any great scramble at the settings. Men who have obtained a footing in the mine have generally the preference over strangers. The captain has generally his price for each pitch; and if it is a new setting for the same pitch, he usually offers it to the party who have already worked it. If they take it, the matter so far is at an end; if not, it is then put up, and the lowest bidders, before a stone which is thrown up falls to the ground, receive the work.

The pitches are set for two months at a time—an arrangement advantageous to all parties; for if the tributers find a pitch poorer than they anticipated, they are not obliged to work it for a greater length of time,—whereas, if it turns out much richer than was expected, the adventurers will be enabled, at the end of that period, to secure their fair share of the produce. The tributers have this further advantage, that should they find the pitch very poor, they may throw it up at the end of a month, although they have taken it for two; and, in such a case, it may be reset to them at a higher rate.

It has been already intimated that, in setting the pitches and giving out tutwork, a preference is usually given to those who have been established in the mine, provided they are disposed to take the work at or near the captain's price. This preference has given rise to the practice of taking "farthing pitches," as they are sometimes called;

that is to say, taking a pitch at the low and merely nominal tribute of a farthing in the pound. The object of doing so is simply to get established in the mine. At the next setting those parties will be on the same footing as those who preceded them in the mine. But advantageous as this appears to be to the adventurers, it is not in reality so. Beyond getting established in the mine, the men have no inducement to work—their tribute being merely nominal. The consequence is, that they waste their time, doing little or no work whilst below, to the obvious detriment of the adventurers. This is now so clearly seen, that in most mines the system of farthing pitches has been discontinued; the adventurers having been all the more inclined to depart from it, from the umbrage which it frequently gave to those who had been long in their employment.

When a pitch is set, it is marked down in the books of the mine as set to such and such a party. Their names or marks are all subscribed to the notification. The party varies in number, according to the nature of the pitch, and the quantity of labour which will have to be expended upon it. Sometimes the party does not exceed four; at other times it consists of six or eight; and occasionally extends to twelve.

Dressing the Ore.—The share of the tributer is determined as to its amount by the value of the ore when ready for market. He has, therefore, not only to extract it from the lode, but also to prepare it for market. This is done on the surface by those whom he employs for the purpose. At every mine there is a large number of surface workers; amongst whom may be seen some men, but the majority of whom are women and boys. They constitute from one-fifth to one-fourth of the whole number employed in and about the mine. These surface workers are almost all in the pay of the tributers or underground men. It is their business to take the ore as it comes from the shaft—to have it stamped, cleaned, and washed, and prepared for the smelters. The larger masses are broken with hammers, generally by women, until the whole pile is in pieces about the size of a large egg. If the ore is very rich, it is then carried to the rollers, between which it is crushed. It is then ready for market. This applies only to the copper ore, which is considered good if it has from ten to fifteen per cent. of metal in it. The preparation of the tin ore is very different. It often comes to the surface with no more than six per cent. of metal in it; but before it is ready for market, and in a state fit to be received by the smelters, it has to be "worked up" until it contains seventy-five per cent. of metal—in other words, the great bulk of the dross must be got rid of. The ore is first taken to the stamps. These have been already described.* As the crushed ore passes from the stamper it is carried by the water to beds, which slightly decline towards one end. The best part of the ore sinks immediately at the upper end of these beds, the dross not sinking until it reaches the lower end. This dross, still containing some metal, is again washed, by being divided into other beds similarly situated, and the process is resumed until little but dross remains. In this way the tin ore is worked up to the requisite quality of seventy-five per cent. When the copper ore is not very rich, it also is put under stamps, and undergoes the process of washing. There are other operations, such as "jigging," &c., all having in view the preparation of the ore for market. It is when sold, after it has been so prepared, that the tributer's earnings are determined; in ascertaining the net amount of which he has, of course, to deduct the wages of those employed by him on the surface for the preparation of the ore. Nor is this the only deduction which has to be made, as will be presently seen. The tin ore is not thus prepared at his cost—being generally bought of him at the top

* See page 257.

of the shaft—the adventurers working it up to the requisite point. Before considering the miner's wages, it will be as well to see him at work.

Underground Work.—Mines are not all equally wet; but no one can expect to penetrate very far into a mine and emerge dry from it. We have, therefore, to go to the "shifting-room," and attire ourselves in a miner's garb. It consists of a suit of thick flannel, with a stout coat over it, heavy shoes for the feet, and a hat generally made strong enough to "bear a good knock." We must also provide ourselves each with a candle. The candle is stuck into a piece of clay, which again is stuck upon the hat, which is of the "wide-awake" shape. Thus equipped, we descend the ladders. As we approach the shaft, we perceive a steam rising from it. This, we are informed, is the breath of the men at work below. The very mine itself seems to breathe. There are, at least, six hundred men at work beneath our feet, at various depths, some one hundred, some five hundred, and others sixteen hundred feet. The ladder is very narrow, with iron bars, and is well nigh perpendicular. The bars are moist and greasy, from the men passing up and down, which makes us cling all the more firmly, considering the unknown depth of the shaft, and the almost perpendicular position of our means of descent. We bid adieu to daylight almost by the time we have reached the first level. There is no one at work in it, so we descend to the second. We pass it, and several others, until at length we reach the seventh level. We are then about four hundred feet under ground—a sufficient depth to bury St. Paul's. We take the level to our right, and pursue it until we reach the men at their work. There is a tramroad along the level for "running the stuff" to the shaft, so that it can be raised to the surface. In some of the smaller mines this is done by boys with wheelbarrows, which with the exception of working the ventilating machines, is the only purpose to which boys are put below. We proceed about one hundred feet in a horizontal course, when we come upon the miners. When they take a pitch, they generally work it *up*, not *down*—that is to say, the men working from the seventh level work up towards the sixth, not down towards the eighth. Their object is to follow the lode, and extract the ore from it, disturbing as little of the non-metallic ground as possible. When the lode is wide enough, they work nothing but the lode, leaving the matter on either side untouched. A miner will thus work in a lode only eighteen inches wide; but if it is narrower than that, he has to clear away some of the "country"—which is, removing a sufficient quantity of the granite, slate, stone, or other substance which may envelop the lode, to enable him to follow it. Those upon whom we have come are engaged at this work. They are preparing to clear away the granite by blasting it. The hole for the powder is made with a "borer," held by one whilst the other strikes it with a large sledge-hammer. The latter is in a state of profuse perspiration, whilst the other is shivering with cold. They are both completely wet—as, indeed, we are ourselves. The man with the hammer has nothing on but his flannel trousers. The beatings of his heart, which are quick and strong, strike painfully upon the ear. He seems to be galloping through life—and so he is; for the miner is generally but a short liver. We leave this part of the level, and take that on the other side of the shaft, which we follow for a considerable distance, until we come to a hole, through which we have to crawl on all fours. We then find ourselves at the bottom of a winze, which we pass, and pursue the level. The men have worked up for a considerable distance, making stages for themselves as they rise into the lode. The ore is carefully separated from the stuff, and is carried over the tramway to the shaft. Such is the merest outline of the work which the mine exhibits. Space will not permit us to go into details here. We return

again to the surface. But to climb a series of perpendicular ladders, reaching as high as St. Paul's, is no joke. We take about half an hour to do it, resting at the different levels as we ascend. We arrive at the top utterly exhausted, and thankful that we have emerged again into daylight.*

Such is the position, and such are the circumstances of the miners when at work. They generally relieve each other every eight hours, each gang working eight hours out of the twenty four. Their tools are chiefly the sledge, the borer, and the pick, with the last of which they remove the dislodged granite, and other stuff, which does not require blasting. At one of the mines near Redruth the tributers have done work in the three hundred fathom level—that is to say, one thousand eight hundred feet below the surface. Their engagement is to be on the ladders by six in the morning, and emerge from the mine about five in the afternoon. Nearly two hours are spent in descending and ascending the ladders. With the exception of the Sundays, the life of these poor fellows is one perpetual night. The temperature is often so high in the level that the men all work naked, ascending, every hour or so, to several fathoms above them, to dip themselves in some pools, which are comparatively cool. But the tributers look with as great contempt upon the tutmen, as the tutmen do upon the surface labourers. Indeed, a tributer will be on the point of starvation before he will take tut-work. Some mines employ upwards of a thousand people; others much less. The Caradon, and other mines which some years ago sprang up in the neighbourhood of Liskeard, afford subsistence to about ten thousand people, including the miners and their families.

Miners' Wages.—The wages, or earnings, are paid once a month; but, to keep the miners and their families going, a portion is paid on account once a fortnight. This is called their "subsist," or, more commonly, "stist." This is objected to by some, as tending to make men lazy. Where the farthing-pitch system is in vogue, it works very badly. In such case the men are not entitled to anything till the end of the first two months; and they do not get their subsist until a fortnight before the day on which they are entitled to their earnings. The consequence is, that they work for six weeks without receiving anything. They are thus driven, by their circumstances, to go into debt with the retail dealers for the necessaries of life. Once in debt, it is very difficult for them to get out of it, and reckless habits frequently supervene.

Drainage.—In this account of mining little notice is taken of the very important operation of draining the mine, which is not to be managed, as in coal mining, by a system of tubbing, because the working of mineral veins is a very different matter from that of removing a coal seam. In early operations, the means of removing water were confined to buckets; and in Cornish mines, the first improvement in drainage was by the pump called the "rag and chain," so named from a quantity of rags or skins, at intervals, bound up to the size of the pump, on a chain or rope, revolving round a cylinder, worked by hand or water-wheel at the surface, which, passing through the pump, forced the water up before it. The next improvement was the common bucket or lifting pump. As long as the notion prevailed that the principle that water could not be raised more than thirty-three feet was applicable to a pump whose bottom was in the water, each lift of pumps was confined to thirty feet; so that in a mine sixty fathoms deep, it would require twelve lifts of pumps, the lower ones supplying the upper by means of cisterns attached to each lift. This method was called "shammeling,"

* This account of mining operations was published some years ago in the "Mining Journal," and is sufficiently graphic and accurate, in respect to Cornwall, to justify re-publication.

and the pumping gear the "shammel engine." It was long considered the *ne plus ultra* of perfection, notwithstanding it was found very troublesome and inconvenient, by filling the shaft with pumps and pump rods. This was the cause of much complication and consequent weakness, and it could only be applied where the quantity to be pumped was moderate, and did not require any rapidity of motion in the pump gear. This defect was severely felt in constant breakages and great friction in working so many buckets. These disadvantages suggested the lengthening of the lift of pumps, and drawing the water to the surface by the power of the water-wheel, in addition to the pressure of the atmosphere. It was soon found that water could be raised thirty fathoms with as much facility as thirty feet, with less wear and tear.

The next and last improvement in drainage was the "plunger" or force pump, by which the weight of the pump-rods and the piston, working in a cylinder at the bottom of the mine, was applied to force the water up through a column of pumps to any height required. It has been found inconvenient to attempt any greater length of lifts than thirty fathoms, or one hundred and eighty feet. The miners are rather fanciful in naming the lifts of pumps; the upper one, which discharges the water at the surface, is called the "tye;" the others, in the order of succession, are the "rose," the "crown," the "lily," the "violet," and so on, the lowest being the "poppy." These improvements required, from the increase of the pressure of water, that the strength of the pumps should be increased; the wood pumps were replaced by iron, and, where the corrosive nature of the water required it, brass pumps, or iron pumps lined with brass, were used.

Within the last half century, there was not a mine in Cornwall one hundred fathoms deep. The Consolidated Mines, at Gwennap, at that time consisted of small mines filled with water. The steam-engine, and an outlay of some £60,000 or £70,000, has enabled the workings to be continued to a depth of upwards of three hundred fathoms, or eighteen hundred feet, under the hill, the perpendicular shaft being nearly fifteen hundred feet deep. The weight of the pump-rods, which have to be lifted every time the pump-buckets require gearing, is little short of one hundred and fifty tons.

Lifting.—With the increased facilities of drainage, corresponding improvements were required for raising the produce of the mines to the surface; the bucket raised by manual labour was succeeded by the kibble drawn up by the winch—a rope or tackle wound round a wood cylinder by an iron handle; then came the "whim," worked by horses, which has continued in use, with various improvements, up to the present time; it is, however, superseded in large mines by drawing machines, worked either by steam or horse-power.

The "whim" is said to have been the invention of a working miner, who, being in a studious mood, was asked by his comrade what was the matter, and replied he had a whim in his head, and his invention was so called accordingly.

Blasting.—On the introduction of gunpowder for blasting the rocks, the miner was subject to continual danger from premature explosions. The hole in the rock, when bored sufficiently deep, had the powder placed in the bottom; an iron rod, or needle, was then inserted, and the hole filled up with sand or clay, rammed in quite tight; the needle was then withdrawn, and a rush inserted. This, when ignited, burned gradually down to the powder, allowing sufficient time for the miner to reach a place of safety. The iron needle at times, when struck with the mallet, would give a spark of fire which ignited the powder, and serious accidents were caused thereby. About thirty years since a copper needle was substituted; but such was the force of

habit, and the iron being cheaper than the copper, that it was only by inflicting fines on the men that the use of iron was discontinued. The copper needle was superseded, about seventeen years' since, by the invention of the safety fuse—being a small hemp cylinder, well saturated with tar, and filled with powder, this is now in general use.

Ticketing Days.—The "ticketing," or weekly sales of ore, form a curious feature in mining. The copper ore, on being raised from the mines and dressed, is put into heaps of several tons, and is well mixed; and a sampler, on an appointed day, fixes on a third or fourth of the dole. The parcel is divided into six doles, two of which are cut in half, and a slice taken off the sides by a shovel. After subdividing and mixing this, a sufficient quantity is put into a bag by each sampler; and this is taken as the sample of the whole. These are carried to the different assay offices, where the ore is pulverized, and an ounce (troy) assayed in a crucible, with proper fluxes; and a bead, or prill of copper, is found among the scoria. If an ounce of ore yield one pennyweight of copper, the produce of that ore will be one in twenty, or five per cent., and so on. The "standard" of copper is the term given by the smelter to denote the price of a ton of metal in the ore, from which standard he deducts a certain price for every ton of ore, or as many as may be required, according to its produce, to give a ton of copper, which sum is considered by the smelter as an equivalent for the returning charge, or expense of reducing the ore to a merchantable state. The returning charge is a fixed one, being the same for poor ores as for rich ones; but, inasmuch as it costs the smelter more to convert a ton of rich ore than a ton of poor, the standard varies with the produce, so as to equalize the matter —hence poor ores fetch a high standard, and rich ores obtain only a low one, because, in the former case, the returning charge more than covers the cost, and in the latter is not supposed to equal it.

A fortnight's interval takes place between the assay and the ticketing, during which time the agents receive answers from their principals as to the price to be offered. Before dinner, tickets, containing offers from the different copper companies, founded on these assays, are produced, and the highest is the purchaser.

Lead Ore Dressing.—The processes adopted in preparing lead ores for the market are not greatly different from those above described, and the mining principles involved are of course the same; although, owing to the fact that the veins are chiefly in hard limestone and gritstone instead of shale and granite, there is a certain amount of modification in details. We may conclude this account with a notice of the preparation of lead in the great mines of Allenheads, in Northumberland, under the management of Mr. T. Sopwith.* The lead raised in these mines

* In a thickness of about two thousand feet of the alternating beds of sandstone, clay, and limestone, which form the strata of the mining districts of Allendale, Alston, and Weardale, there is one single stratum of limestone called the "great limestone," the veins in which have produced nearly, if not quite, as much ore as all the other strata put together. Its thickness—which is tolerably uniform over several hundred square miles of country—is about sixty feet. In a great thickness of strata *above* the great limestone, only two beds of that rock are found. One of these is called "little limestone;" it is from ten to twelve feet thick, and is seventy-five feet above the top of great limestone. The other is still more inconsiderable, being only three or four feet thick, and is four hundred and forty feet above the great limestone. Beneath the great limestone are several beds of the same description of rock, viz., at distances respectively of thirty, one hundred and six, one hundred and ninety, two hundred and fifty, and two hundred and eighty-seven feet; and the thickness two, twenty-four, ten, fifteen, and thirty-five feet. These are known by descriptive local names, and comprise all that are of significance as regards lead-mining operations.

amounts to about one-fourth part of the whole quantity raised in England, and one-tenth that of the whole of Europe.

The produce of the mineral veins varies from pure galena to masses of rock in spar, in which the ore is so thinly disseminated as not to repay the trouble of extraction; and the process of preparing and dressing, after the extraction of the ore from its place in the mine, consists of the pure samples of ore being picked out, washed and sized, ready for being smelted at once, without further operations—and also of the poorer samples being washed and separated by an iron grate or sieve into two sizes, the larger having to be ground between rollers to reduce it to the same size as the smaller, which had passed the grate. When reduced to this stage, the whole is ready for an operation called "hotching." This consists in placing the ore in a tub with water—the bottom of which tub is a sieve—and subjecting the whole to a rapid vibratory vertical movement, or shaking, by which a separation of the ore takes place. The water so far lessens the weight as greatly to facilitate the downward movement of the ore, which of course is much heavier than the spar and other materials connected with it. The vibratory movement is sometimes given by manual labour: a long arm, moving with a spring, is jerked up and down by a strong lad jumping on a raised stand, so as to produce the required motion. The same results may be obtained by machinery. The ore being thus prepared and acted on, the uppermost part is entirely waste or refuse, and that at the bottom of the tub consists of ore ready for smelting. That which passes through the sieve requires clearing from foreign substances and dressing, in a contrivance called a *buddle*, which is not unlike the hotching tub above described.

In all operations where a stream of running water is employed to wash lead ores, it is obvious that many of the smaller particles will be carried away with the stream. These particles are allowed to settle by their specific gravity in what are called slime-pits, being merely reservoirs in which the water passes over a long space with a very tranquil movement.

It is not intended here to describe in detail the methods of dressing and preparing the ore for each different metal, or to mention the peculiarities appertaining to the ores themselves. These are matters belonging to the practice of metallurgy, and would involve an extension of the present work beyond its proper limits. They may, however, be found elsewhere described, by those who require this kind of technical information. *

Practical Uses of Geology.—In concluding this part of our subject—a department of science worthy of every attention, and not to be mastered without much careful study—we may with propriety refer once more to the advantage of geological pursuits generally, but more especially in this matter of mining, and other practical applications already described.

It occurs, as a matter of fact concerning the distribution of mineral substances in the earth, that materials of whatever value are rarely so distinctly presented, or so readily available, that we can be sure of finding them at once and without search. Those vast quarries of building stone, slate, and marble—those mines of coal and iron, which astonish us by the infinite complication and the extent of their workings, are rarely indicated at the surface by anything more definite than some general peculiarity

The Allenheads mines being situated for the most part at depths from the surface varying from two hundred to six hundred feet, are drained partly by ordinary water-wheels, and partly by new hydraulic engines invented by Mr. W. G. Armstrong.

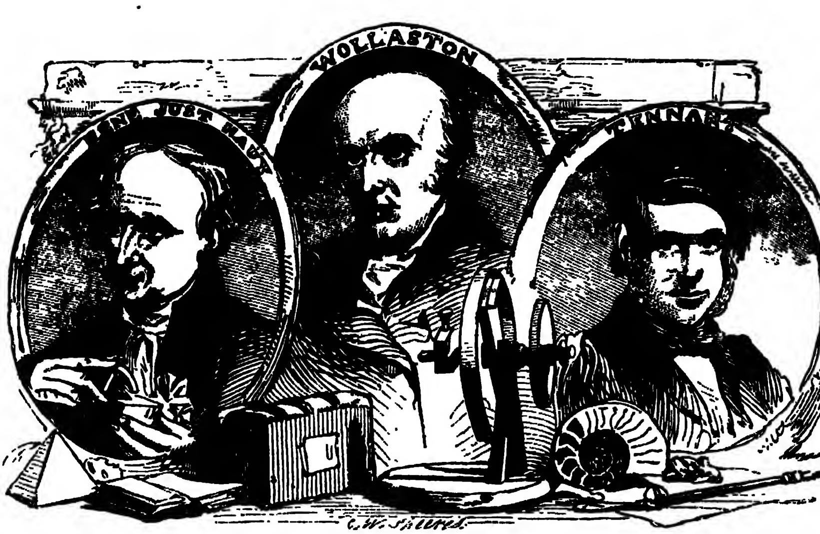
* An account of stamps, crushers, and jigging machines has already been given in our account of gold washing and crushing. See page 257.

by no means always important. Sometimes, indeed, the discovery of such hidden treasures has been the work of accident; but although accident may lay them bare, it cannot render them useful. A multitude of examples might with great ease be cited, in which substances of great value have lain unnoticed and despised for years, until some one has appeared who had knowledge as well as observation. Then the value appears, and the world is astonished that no one made the useful discovery before. In fact, however, the cause of the non-discovery was very simple, as it generally is, and had its foundation in *ignorance*. In all cases in nature, but especially in such as those we have been considering, an acquaintance with nature—with her laws, her operations, and her history—is directly useful; and it is and must be so to every man, whatever his business is. Varied as the operations and appearances in nature may be, they are all conclusions derived from the action of a very few great and universal laws. There is nothing truly arbitrary, and combinations of similar causes always produce similar effects. But if this is the case—and the more we study nature, the more truly we find it to be so—how much does it not add to the dignity, as well as the usefulness of science—for science is nothing more than this knowledge of nature and a familiarity with the operations of nature's laws. Every one who observes nature honestly and carefully—who makes himself acquainted with what others, working in the same field, have done—who thinks and reflects on what he sees—and who endeavours to draw conclusions without giving his prejudices undue weight—cannot fail to derive from this habit of availing himself of opportunities, some great advantages which will place him in a better position than his less informed neighbour or competitors. In this way, all science is immediately and practically available; but of all departments, few, perhaps, are more directly so than geology. As there are none either amongst the agriculturists or manufacturers who can dispense with the materials existing around them, and only modified by them; as all deal with the earth's surface, or with some of the substances obtained from beneath it; so we may be assured that all will be benefited by some knowledge or other of its nature and history. It is not only the miner and the quarryman to whom a knowledge of geology is useful; it is equally necessary to the engineer and the architect, and perhaps still more so to the farmer; while, in not a few cases, the political economist and the legislator find it necessary to call in the assistance of him who, in studying the earth's structure, learns the nature of those laws which have governed its formation, and can foresee consequences which must result from the neglect of obedience to them. In this way it is that practical geology, which a few years ago was hardly known, except as forming part of the knowledge of some few engineers and miners, is now not only recognised, but has become of the most vital importance. The practical geologist is now called in to assist the engineer, the agriculturist and the miner, to give an opinion as to the value of property, and to decide points on which the health, wealth, and future prospects of large populations depend.

But although geology is now a profession requiring early study and long experience, it is by no means necessary to devote a lifetime to theoretical pursuits in order to observe facts and obtain useful results; and we may safely say that there is not one intelligent, thinking man, having the ordinary means of obtaining and dispensing information, who is not in a position to directly advance the interests of science by his own efforts, and avail himself of the mass of scientific lore that has been accumulated by his fellow men. But this must be properly understood. It is not, on the one hand, the man who believes and is astonished at everything put before him; nor is it, on the other, he who

begins by doubting everything except the whims of his own fancy and imagination; nor is it he who begins with prejudices, and will not listen to any one who throws doubt on his preconceived notions,—who can be in this way useful, or can be benefited by the advance of science. All these are men who retard progress, and remain to the end of their lives as ignorant as they started. On the contrary, he who begins by doubting and questioning his own first impressions, his preconceived notions, and his natural prejudices, and who is contented to learn and labour, and ponder on what he learns and sees; he who advances from fact to fact, knitting them all together into one firm and compact web; who lets nothing escape his observation, and admits nothing into his storehouse which he does not know to be genuine,—it is such a one who is really a valuable man in science. Such men, like Davy in chemistry, like Watt in mechanics, and like a host of other brilliant examples of the nobility of nature,—such men rise from time to time from the ranks in which we all commence our work—they rise from the only natural level—that of utter ignorance—to a higher and higher position in science and in society—they first attain their level among the multitude who are advancing and rising around them, and they stand forth at last amongst the highest, the best, and the most useful of their race—examples of what honesty, truth, and energy can do when combined with high intellect and genius. None rise to these heights without truth and energy, for they are as necessary as genius itself; and by the advances thus made science continually progresses. By taking his share in the observation and reflection, as well as the work, each person may in his turn and in his place become a contributor to that vast mass of knowledge which is being treasured up on every side. Numbers are at work upon this. Day after day the treasure is larger, and the value greater. Some work with their hands, others arrange and compare; some are in the house, and others in the field; some occupy one post, and some another; some are pioneers, some form the main body; some are always in the van; many lag behind, and would willingly stand still; but the progress is ever onwards—the result never attained; there is always abundant work to do, and there is reward for work done. Every investigation that has the discovery of truth for its object is good and useful; and every one who works for his race as well as himself is a better subject, a better citizen, and a better man, than he who sits by doing nothing, or endeavouring to persuade himself that he can find nothing suited for him to do.

D. T. ANSTED



CRYSTALLOGRAPHY AND MINERALOGY.

Crystallography, while it is of great value to the chemist and natural philosopher in their researches, is so important a branch of Mineralogy, that it is impossible to make any progress in that science without some knowledge of its principles. We therefore intend to make our Treatise on Crystallography serve as an introduction to Mineralogy. The hardness, specific gravity, chemical composition, and other properties of minerals, as well as the localities in which they are found, and their scientific arrangement, will follow the Treatise on Crystallography.

Crystallography.—In the mineral kingdom a great variety of solid bodies are met with, bounded by plane smooth surfaces. These bodies are called crystals, and it is the province of the science of Crystallography to investigate their mathematical properties, to classify and arrange them. The surfaces of crystals are not always plane; they are sometimes curved; but these curved surfaces are comparatively rare. Crystals are not confined to the mineral kingdom; they occur very frequently among the products of the chemical laboratory. Almost all the salts, and a great many other substances, under favourable circumstances, assume the form of crystals.

Some crystals are very simple in their forms, and present solids remarkable for their symmetry; while others are exceedingly complex, being bounded by more than a hundred different surfaces.

We are ignorant, as yet, of the manner in which the majority of crystals belonging to the mineral kingdom are formed. Very few can be reproduced by the chemist; and those which can, are generally smaller than the natural ones, and present few of their

modifications. Crystals of quartz occur of an immense size in nature, some single crystals weighing many pounds. It is doubtful if any crystals of this substance have been obtained artificially. Crystals of carbonate of lime occur in nature of almost every size, and in almost numberless varieties of form; while the artificial crystals are almost microscopical in character. The diamond, which is carbon in a crystallized state, has never been produced by art; but some very minute crystals of a few of the other gems have been formed by the chemists.

Though we are ignorant of the means by which the great majority of crystals have been formed in the great laboratory of nature, we can crystallize an immense variety of substances. Nothing can be more interesting, and at the same time more instructive to the student of crystallography, than to watch the process of crystallization for himself, and observe the gradual growth of crystals.

Artificial Crystals.—Crystals may be obtained by various methods. Most of the salts, as well as some other substances which are soluble in water, deposit crystals as their solutions are gradually evaporated. Bismuth, and most other metals, assume the crystalline form as they pass from the fluid to the solid state after being melted. Some bodies become crystallized by the process of sublimation. Crystals are formed by the electro-galvanic decomposition of some solutions; thus, tin crystallizes by the reduction of a solution of its protochloride by a galvanic current. Crystals of sulphur may be obtained in three ways,—by sublimation, by the evaporation of its solution in bisulphide of carbon, and by cooling from a state of fusion.

Crystals, Crystalline, and Amorphous Substances.—All solid substances which do not owe their structure to the vital forces of the animal or vegetable kingdom are crystals, crystalline, or amorphous. Crystals have been already described. A crystalline body consists of a confused aggregation of minute or imperfect crystals: and an amorphous body is one in which, as its name implies, no form or structure can be observed. Sugar-candy consists of crystals of sugar; loaf-sugar is crystalline, and barley-sugar is amorphous. We meet with crystals of carbonate of lime in calcareous spar and arragonite; marble is a crystalline, and chalk an amorphous form of the same substance.

Faces, Edges, Angles, and Axes of Crystals.—The plane surfaces by which a crystal is bounded are called its faces. An edge is the line formed by the union of two faces. The solid angle of a crystal is produced by the union of more than two faces, and may be three-faced, four-faced, six-faced, &c. The plane angles are the angles on a face, bounded by the intersection of its boundary edges. Axes are imaginary lines, drawn through a crystal for the convenience of calculation, or for the purpose of describing its geometrical properties. Crystalline forms are the simplest mathematical solids in which crystals occur, or to which their faces are parallel.

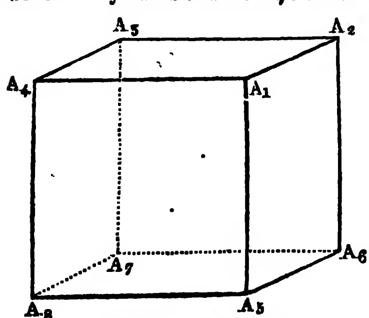


Fig. 1.—The Cube.

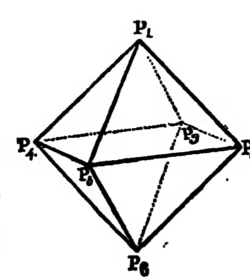


Fig. 2.—The Octahedron.

If as much common salt be thrown into boiling water as it will dissolve, beautiful cubes will be seen to form rapidly on its surface as it cools, as well as on the sides of the vessel in which it is contained. The same thing will occur more slowly, if a saturated solution of salt in cold water be allowed to evaporate spontaneously. A warm solution of alum will deposit octahedral crystals on strings suspended in it, as well as on the sides of the vessel containing it as it cools. The surfaces of the cube are all squares, those of the octahedron equilateral triangles; the cube is bounded by six squares, the octahedron by eight triangles.

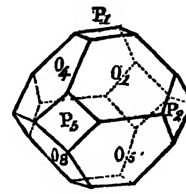


Fig. 3.

Compound Crystalline Forms.—If an octahedral crystal of alum be left suspended, at the ordinary temperature of the atmosphere, for a day or two, in the solution of alum in which it was formed, though the crystal will increase in size, its form will generally be altered. The six solid angles, formed by the junction of four of the equilateral faces, will be found replaced by flat square surfaces; so that the crystal will present the appearance represented in Fig. 3, where the eight faces, bounded by six edges, and marked O_1, O_2, &c., O_8, will be parallel to those of the octahedron first formed by the solution.

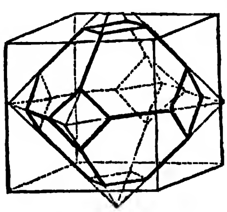


Fig. 4.

If the six square faces, marked P_1, P_2, &c., P_6, be produced till they intersect one another, these intersections will give the outline of a cube, while the faces O_1, O_2, &c., O_8, being similarly produced, will complete the figure of an octahedron, as shown by Fig. 4.

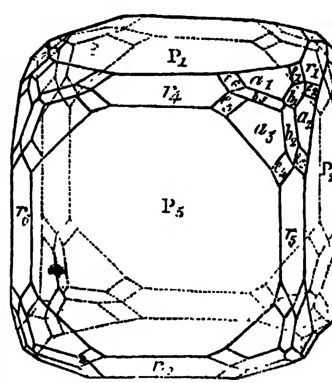


Fig. .

Such a crystal as this is called a combination of the forms of the cube and octahedron. The faces which, being produced, form a cube, are called the cubical faces; and those which form the octahedron, octahedral faces.

Far more complicated forms are found in nature. Fig. 5 represents a cube of fluor

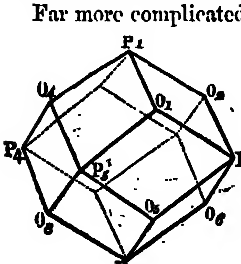


Fig. 6.
Rhombic Dodecahedron.

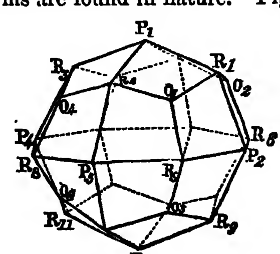


Fig. 7.
Twenty-four-faced Trapezohedron.

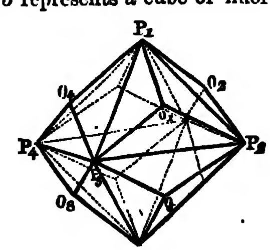


Fig. 8.
Three-faced Octahedron.

spar, every edge of which is modified or replaced by a plane surface, inclined to the sur-

face of the cube; and every solid angle of the cube is replaced by twelve planes. The crystal has therefore one hundred and fourteen faces.

The six faces, P_1, P_2, P_3, &c., P_6, are parallel to the faces of the cube (Fig. 1).

The faces, r_1, r_2, r_3, &c., r_{12}, which replace the edges of the cube, are parallel to a twelve-faced figure, called the *Rhombic Dodecahedron* (Fig. 6).

The twenty-four faces a_1, a_2, a_3, &c., which modify each solid angle of the cube, are parallel to the surfaces of the twenty-four-faced trapezohedron, bounded by twenty-four similar and equal four-sided faces, called *deltoids*, or *trapeziums* (Fig. 7).

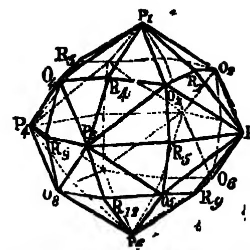


Fig. 9.—Six-faced Octahedron.

The twenty-four faces, b_1, b_2, b_3, &c., are parallel to the surfaces of the twenty-four-faced figure called the three-faced octahedron, each of whose faces is a similar and equal isosceles triangle (Fig. 8).

And the forty-eight faces, c_1, c_2, c_3, c_4, c_5, c_6, &c., are parallel to the surfaces of a forty-eight-faced figure, called the six-faced octahedron, each of whose faces are scalene triangles, similar and equal to each other (Fig. 9).

Modifications of Forms.—Crystals of simple forms, such as the octahedron, are sometimes formed with as much accuracy as the geometrical solid; but at other times the faces are so modified as to render it difficult, at first sight, to recognise the form to which they belong. The three accompanying figures (Figs. 10, 11, and 12) represent modifications of the octahedron frequently observed among the crystals

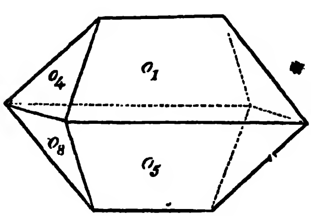


Fig. 10.

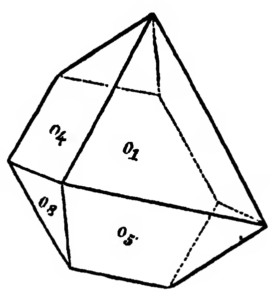


Fig. 11.

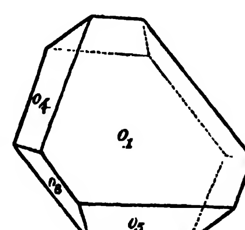


Fig. 12.

of alum. On examination, it will be found that the faces o_1, o_2, &c., o_8, are each parallel to a face of an octahedron; and that the inclination of any one face, such as o_1 on any of the adjacent faces, such as o_4, or o_5, is an angle of 109° 28′, as it is in the regular octahedron.

Forms of Crystals independent of the size of their Faces and Edges.—From what has been stated, with regard to the octahedron, it appears that the geometrical form, to which the faces of a natural crystal are referred, is independent of the size of the face, or even the form of its outline. Thus, the faces of an octahedron are all equilateral triangles, while some of the faces in the three preceding figures are bounded by four edges, as o_1 and o_5 (Fig. 10), o_4 and o_8 (Fig. 11), and some by six, as o_1 (Fig. 12). A regular octahedron, or cube, may be of any size, from one requiring a

microscope to perceive it, to one whose edges are several inches in length. The faces of a compound crystal are always referred to the simplest symmetrical solid to which they are parallel. This parallelism is determined by the measurement of the inclination of one face to another. This inclination is determined by instruments called goniometers, which will be described hereafter.

Cleavage.—Some minerals are found to split, or cleave, with greater ease and readiness in some directions than others. In some cases, as in calcareous spar and fluor spar, this cleavage takes place with great facility, and displays very smooth surfaces. The cleavage is generally parallel to some crystalline form; that of calcareous spar being parallel to the six faces of a figure called the rhombohedron, and that of fluor spar parallel to the eight faces of the octahedron.

If a cube of fluor spar, A_1, A_2, &c., A_8, have diagonals, $A_1 A_3$, $A_2 A_4$, joining the opposite angles of its square faces, scratched upon them. It will be found that a knife being applied, with its edge on one of the diagonals $A_1 A_3$, and the blade of the knife in the same plane with the triangle $A_1 A_3 A_8$, a smart blow from a hammer, on the back of the knife, will detach the solid pyramid A_1 A_3 A_8 A_4, from the cube. In a similar manner, the pyramids A_1 A_3 A_6 A_2, A_1 A_8 A_6 A_5, and A_3 A_8 A_6 A_7, may be removed, leaving a regular tetrahedron, A_1, A_3, A_8, A_6, as the nucleus of the cube.

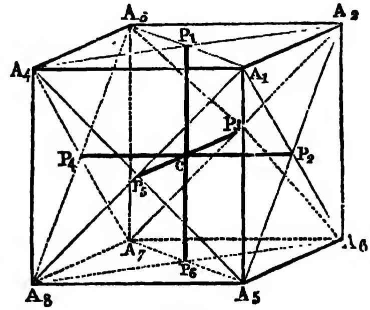


Fig. 13.

By removing the four pyramids whose vertices are, A_3, A_1, A_8, and A_6, another tetrahedron in the position A_2 A_4 A_7 A_5, might have been obtained.

Nature thus affords a demonstration of the 1st proposition of the 15th Book of Euclid—"*How to inscribe a regular Tetrahedron in a Cube.*"

By removing the eight solid pyramids, whose vertices are respectively A_1, A_2, &c., A_8, and replacing the removed fragments, we should see, within our transparent cube of fluor spar, a regular octahedron P_1 P_2 &c., P_6, inclosed within the cube, and regularly inscribed in it, as the octahedron is inscribed in a cube by the 3rd Prop. of the 15th Book of Euclid.

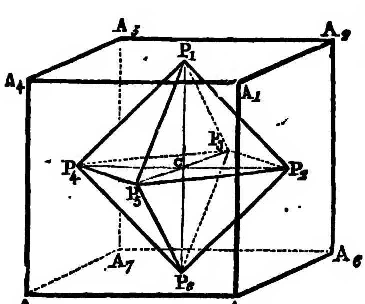


Fig 14.

Systems of Crystals.—We have seen that one substance, such as fluor spar, presents on its crystals faces parallel to several different mathematical symmetrical solid forms. All these forms can be shown to have certain mathematical relations to the cube or the regular octahedron. Other substances, whose crystals occur in the form of the cube or octahedron, or have faces parallel to these forms. present us with crystals either in the form, or with faces parallel to the same mathemathical solids.

These solids, thus associated in nature, and possessing certain mathematical properties in common, are classed together in one system, called the cubical or octahedral system.

Other substances occur in forms similar to, or with their faces parallel to, other mathematical solids, differing in their mathematical properties from those of the cubical system. These forms are classed together under other systems.

It may be observed, that faces parallel to the forms of one system are not found on the same crystal combined with faces parallel to the faces of forms belonging to a different system of crystallization. Thus, faces parallel to the eight faces of the regular octahedron are found on crystals, associated only with faces parallel to the forms of the cubical system, and not to forms belonging to the other systems.

Some one form may be taken as the type or primitive form, from which all others of the same system may be easily derived. This typical or primitive form is quite arbitrary; and it may be either a prism, an octahedron, or some other simple form.

1st system.—The cubical, or octahedral; according as we consider the regular cube or regular octahedron its typical or primitive form.

2nd system.—Square, prismatic, or pyramidal. Typical form, a prism on a square base, or octahedron on a square base.

3rd system.—Rhombohedral, or hexagonal. Typical form, the rhomboid or the hexagonal prism.

4th system.—Prismatic, or rhombic. Typical form, a right prism on a rhombic base, or octahedron on a rhombic base.

5th system.—Oblique. Typical form, an oblique prism on a rhombic base, or oblique pyramid on a rhombic base.

6th system.—Anorthic, or doubly oblique. Typical form, a doubly oblique prism or octahedron.

FIRST SYSTEM.—THE CUBICAL.

This system is called the *cubical* or *tesseral* (*tessera*, a cube), if its forms are regarded as derived from the cube; the *octahedral*, if its forms are derived from the regular octahedron. It is also called the *regular* or *isometrical*, from the properties of its axes.

The axes of this system will be described under the CUBE.

The *holohedral forms* of this system, or those forms which possess the highest degree of symmetry, are the *cube, octahedron, rhombic, dodecahedron, three-faced octahedron, twenty-four-faced trapezohedron, four-faced cube*, and the *six-faced octahedron.*

From each of these, with the exception of the cube and rhombic dodecahedron, other forms are produced by the development of half their faces; these are called *hemihedral.*

The hemihedral form of the octahedron is the *tetrahedron*; that of the three-faced octahedron, the *twelve-faced-trapezohedron;* that of the twenty-four-faced trapezohedron, the *three-faced-tetrahedron*; and that of the four-faced cube the *pentagonal dodecahedron.* The six-faced octahedron has two hemihedral forms; the *six-faced tetrahedron* and a *twenty-four-faced trapezohedron* having two sides of its trapezoidal face parallel. Of these, two—the *pentagonal dodecahedron* and the *hemihedral twenty-four-faced tra-*

pezohedron—have their faces parallel to one another, in pairs, and are called *hemihedral forms with parallel faces.*

The other hemihedral forms are called *hemihedral forms with inclined faces.*

The Cube.—The cube or hexahedron (six-faced), is a solid bounded by six square faces; it has eight solid four-faced angles, A_1 A_2, &c., A_8 (Fig. 15), and twelve edges, A_1 A_2, A_3 A_4, &c. Every face is inclined to its adjacent faces at an angle of 90°.

Axes of the Cube and the Cubical System.

Cubical Axes.—If diagonals be drawn through the opposite angles of the faces

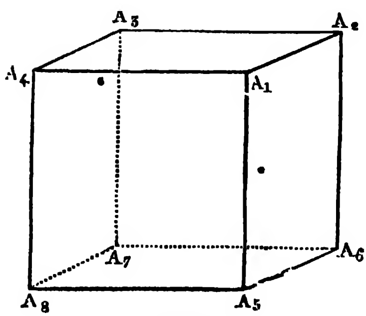


Fig. 15.

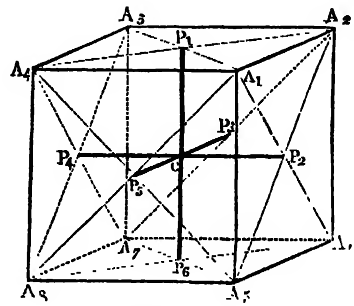


Fig. 16.

of the cube, they will intersect one another in the centre of each face. Let P_1, P_2, P_3, P_4, P_5, P_6 (Fig. 16), be these six centres.

Join P_1 P_6, P_2 P_4, and P_3 P_5.

These three lines will intersect one another in the point C. They are called the *regular or rectangular axes* of the cubical system.

Reckoning from C, which is the centre of the cube, each of the six lines, CP_1 CP_2, &c., CP_6, are equal to each other, and they are each perpendicular to a face of the cube at the point P, and the adjacent ones are inclined to each other at an angle of 90°.

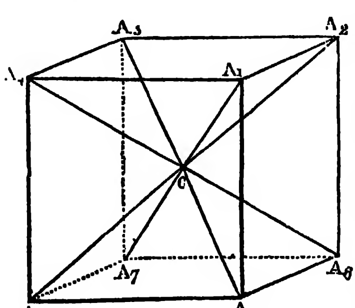


Fig. 17.

Octahedral Axes.—If lines be drawn from one solid angle of the cube to the solid angle opposite to it, we shall then have four lines, A_1 A_7, A_2 A_8, A_3 A_5, and A_4 A_6 (Fig. 17), intersecting one another at the same point, C, as the cubical axes. These lines are all equal, and inclined to one another at an angle of 70° 32′.

The eight lines CA_1 CA_2, &c., CA_8, are each perpendicular to a face of the octahedron inscribed in the cube. They are therefore called the *octahedral axes.* If C P_1 or C P_2 be taken as the unit, CA_1 CA_2, &c., will each be equal to $\sqrt{3}$.

Rhombic Axes—Let B_1 B_2 B_3, &c., B_{12}, be the centres of each of the twelve edges of the cube. Join B_1 B_{11}, B_2 B_{12}, &c. These six lines will intersect one another in C, the centre of the cube. Each of the lines CB_1 CB_2, &c., CB_{12}, are equal to one another, and perpendicular to a face of the rhombic dodecahedron inscribed in the cube. They are called the ***rhombic axes***, and the adjacent ones are inclined to each other at an angle of 60°. Taking CP_1, the cubical axis as $= 1$, CB_1, CB_2, &c., each $= \sqrt{2}$.

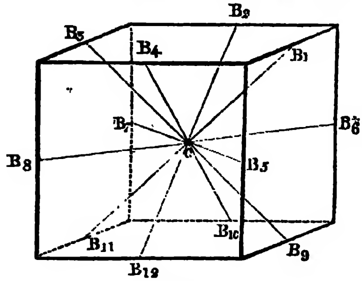


Fig. 18.

Normals.—A line drawn through a given point perpendicular to the face of a crystalline form, is called a ***normal*** to that face from the given point. Thus the cubical axes are normals to the faces of the cube from the point C, and the octahedral and rhombic axes are normals to the faces of the octahedron and rhombic dodecahedron from the same point.

To draw a Cube.—The perspective used in drawing crystals is called isometrical. In this, the lines which in the ordinary system of perspective are drawn converging to a point, are drawn parallel to one another. It is the most convenient method for representing geometrical solids.

Describe a square, A_1 A_5 A_8 A_4 (as at Figs. 2 and 15), of any convenient size. Draw the line A_1 A_2, at an angle of about 30° to the line A_1 A_4. Then, through A_4 A_5 and A_8 draw A_4 A_3, A_5 A_6, and A_8 A_7 parallel to A_1 A_2. Make A_1 A_2, A_4 A_3, A_5 A_6, and A_8 A_7 each half the length of one of the sides of the square A_1 A_5 A_4 A_8.

Join A_2 A_3, A_7 A_6, A_2 A_6, A_3 A_7, and the representation is completed.

Crystallographical Symbol for the Cube.—The relations of the faces of the cube to its *rectangular* or *cubical axes*, affords a ready means for adopting a symbol which shall express some of its properties. It will be readily seen that every face cuts one of the cubical axes, and is parallel to the directions of the other two. A line, or plane, which is parallel to another line or plane, is said, in mathematical language, to cut it at an infinite distance, and as ∞ is the symbol for infinity, regarding CP, the perpendicular distance of the cube from its centre as the unit, the symbol 1, ∞, ∞ signifies that every face of the cube cuts one of the axes at distance 1 from its centre, and the other two axes at an infinite distance. Naumann's symbol for the cube is $\infty O \infty$, Miller's, 100, and Brooke and Levy's modification of Haüy, P.

Generally in Naumann's symbols the figures represent the distances at which the faces of the form cut the rectangular axes, the figure 1 being always understood. In Miller's they signify the parts of some arbitrary unit, at which the faces cut the axes. In Brooke and Levy's, b^m indicates that every plane is parallel to an edge of the cube, m being the ratio which the two edges cut by the plane bear to one another; a^m and b^h b^k b^l represent that the planes are parallel to one cutting off a solid angle of the cube the figures m, h, k, and l, indicating the ratios of the cut edges of the solid angle.

Net for the Cube.—One of the simplest, most useful, and at the same time most inexpensive means of modelling the forms of crystals, is to draw their faces on pasteboard, and arrange them in such a manner that some of the edges being cut partially, and others quite through the pasteboard, the whole may readily fold up into the required form. The loose edges being glued together, a firm model will be formed in a few

minutes. A drawing of the faces of a solid, arranged so that the model may be folded up from a single piece of pasteboard, is called *a net.*

To make a net for the cube, describe a square equal to a face of the required model, and arrange six such squares in the manner represented in Fig. 19. If a knife be drawn so as to cut the pasteboard half through along the light lines, and quite through along the dark ones, the figure will readily fold into the form of the cube.

In this and the other nets which will be described, it is very convenient to draw one face on tracing paper. The other faces may then be readily pricked off from this one on the pasteboard, in the required form, with greater ease, and even more accurately than by describing each face geometrically. It will also be found convenient to leave a margin to one edge where two edges are to be glued together. Glue is better than paste, as it dries more quickly, and does not, like paste or gum, warp the surfaces of the model.

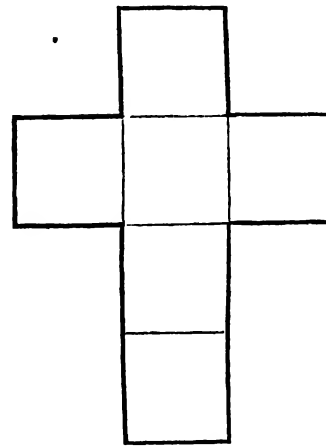


Fig. 19.

Minerals whose crystals occur in the form of the cube, or present, in their modifications, faces parallel to it :—

Alabandine (sulphuret of manganese).
Altaite (telluride of lead).
Alum.
Amalgam.
Analcime.
Argentite (sulphuret of silver).
Blende (sulphuret of zinc.
Boracite.
Bornite (purple copper).
Bromite.
Clausthalite (seleniuret of lead).
Cobaltine (bright white cobalt).
Copper.
Cubane.
Cuprite (red oxide of copper).
Diamond.
Embolite.
Eulytine (bismuth blende).
Fahlerz (gray copper).
Fluor.
Franklinite.
Gahnite (automalite).
Galena (sulphuret of lead).
Garnet.
Gersdorffite.
Grünauite (sulphuret of nickel and bismuth).
Hauerite.
Hauyne.
Iridium.
Iron.
Iserine.
Kerate (muriate of silver).
Lerbachite (seleniuret of lead and mercury).
Linnéite (sulphuret of cobalt).
Magnetite (magnetic iron ore).
Naumannite.
Percylite.
Periclase.
Perowskite.
Petzite (telluride of silver).
Pharmacosiderite (arseniate of iron).
Platinum.
Pyrite (sulphuret of iron).
Pyrochlore.
Rammelsbergite (white arsenical nickel).
Safflorite (arsenical cobalt).
Sal ammoniac.
Salt.
Silver.
Skutterudite.
Smaltine (tin white cobalt).
Sodalite.
Stannine (sulphuret of tin).
Steinmannite.
Sylvine.
Tennantite.
Ullmanite (sulphuret of nickel and antimony).
Voltaite.

Minerals whose crystals cleave parallel to the faces of the cube,—those printed in italics *indicating that the cleavage is easy and perfect :—*

Alabandine.
Altaite.
Analcine.
Argentite.
Chromite.
Clausthalite.
Cobaltine.
Cubane.
Embolite.
Franklinite.
Gahnite.
Galena.
Gersdorffite.
Hauerite.
Iridium.
Iron.
Lerbachite.
Linnéite.
Magnetite.
Naumannite.
Periclase.
Perowskite.
Pyrite.
Pyrochlore.
Salt.
Skutterudite.
Smaltine.
Spinelle.
Stannine.
Steinmannite.
Sylvine.
Ullmanite.

The Octahedron—Call the regular octahedron, to distinguish it from other octahedrons, whose faces are not equilateral triangles. This form is bounded by eight equal and similar faces, each being an equilateral triangle. It has *twelve equal edges*, $P_1 P_2$, $P_2 P_3$, &c., and *six four-faced solid angles*, $P_1 P_2 P_3 P_4 P_5$, and P_6. Each face is inclined to its adjacent face at an angle of 109° 28.′

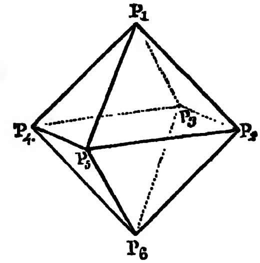


Fig. 20.

To draw the Octahedron—A cube being described as previously directed—

The centre of each face $P_1 P_2$, &c., P_6, may easily be found by joining $A_1 A_3$, $A_2 A_4$, &c. Join $P_1 P_6$, $P_2 P_4$, and $P_3 P_5$, meeting in C. These are the cubical axes of the cube. Join $P_1 P_2$, $P_1 P_3$ $P_1 P_5$, $P_2 P_3$, $P_3 P_4$, &c., as shown in Fig. 21, and an octahedron, $P_1 P_2$, &c., P_6, will be delineated inscribed in the cube; or two equal lines, $P_1 P_6$, and $P_2 P_4$ may be drawn perpendicular to one another, and intersecting each other in their centre C; draw CP_3, making an angle of 30° with CP_2, produce CP_3 to CP_5, and make CP_3, CP_5, each half of CP_2; and join the points $P_1 P_2$, &c., as before.

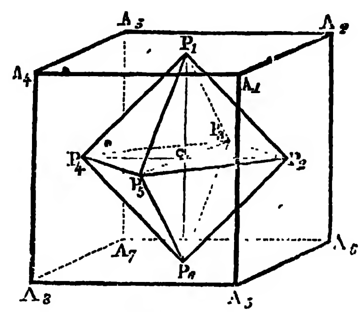


Fig. 21.

Relations of the Octahedron to the different Axes of the Cube.—From the previous figure it is evident that the cubical axes join the opposite solid angles of the octahedron.

Let $P_1 P_2 P_5$ (Fig. 22), be one of the faces of the octahedron. Bisect $P_1 P_2$, $P_2 P_5$, and $P_1 P_5$ in R_1, R_5 and R_4. Join $P_1 R_5$, $P_2 R_4$, and $P_5 R_1$.

These lines will intersect in O and each of the lines RO will be one-third of the line PR.

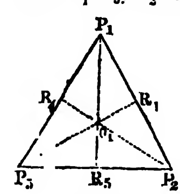


Fig. 22.

Suppose every face of the octahedron similarly divided, as shown in Fig. 23.

If now the octahedral axes $A_1 A_7$, $A_2 A_8$, &c., be drawn, joining the opposite solid angles of the cube, as in Fig. 17, each octahedral axis will pass through the face of the octahedron inscribed in the cube at the point O (Fig. 23), and will be perpendicular to it. The distance of O, from the centre of the cube, will be one-third of that of A; so that the octahedral axes of the octahedron will be a third of the octahedral axes of the cube in which it is inscribed.

The rhombic axes of the cube being drawn by joining the centres of its opposite edges, as in Fig. 13, these axes will pass through the centre of each edge of the octahedron, as R_1 R_4 and R_5 (Fig. 23). The distance of R, from the centre of the cube, will be one-half of that of B. Hence the rhombic axes of the octahedron will be one-half of the rhombic axes of the cube in which it is inscribed.

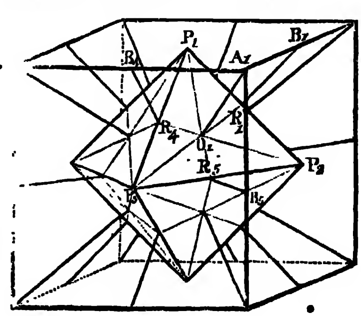


Fig. 23.

Symbols.—Each face of the octahedron cuts the three cubical axes at an equal distance CP from the centre of the cube, and taking CP as unity, 111 will be the symbol which expresses this relation of the faces of the octahedron to the cubical axes. Naumann's symbol for the octahedron is O, Miller's 111, and Brooke and Levy's modification of Haüy A^1 or a^1.

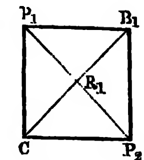


Fig. 24.

To describe a Net for the Octahedron.—If a model of a cube be formed by glueing the edges of six square pieces of glass, the different forms of the cubical system may be modelled of such a size as to be inscribed in the cube in the manner represented in their respective figures.

Describe a square P_1 B_1 P_2 C (Fig. 24), having its side P_1 B_1 equal to half the edge of the cube in which the model of the octahedron is to be inscribed.

Draw the diagonals P_1 P_2, and B_1 C; on either of these diagonals, as a base, describe an equilateral triangle (Fig. 22), and arrange eight such equilateral triangles, as in Fig. 25. When this net is cut out along the dark lines, and partially along the lighter lines, it will fold up into an octahedron, whose solid angles will just touch the centres of the faces of a cube the edge of which is twice the length of the line PB. In this and the following forms, the face of the crystal is described of such a size that the model may be inscribed in a cube whose edge is one inch in length. The faces on the net are only made half the size.

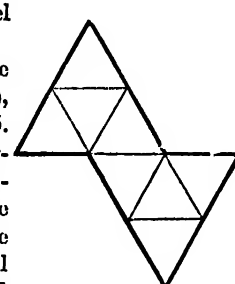


Fig. 25.

Minerals whose crystals occur in the form of the Octahedron, or whose modifications present faces parallel to it:—

Alabandine (sulphuret of manganese).
Alum.
Amalgam.
Argentite (sulphuret of silver).
Arquerite.
Arsenite (oxide of arsenic).
Blende (sulphuret of zinc).
Boracite.
Bornite (purple copper).
Bromite.
Chromite (chromate of iron).
Cobaltine (bright white cobalt).
Copper.
Cuprite (red oxide of copper).
Diamond.
Eisennickelkies.
Embolite.
Eulytine (bismuth blende).
Fahlerz (gray copper).
Fluor.
Franklinite.
Gahnite (automalite).
Galena (sulphuret of lead).
Gersdorffite.
Gold.
Grünauite (sulphuret of nickel and bismuth).
Hauerite.
Hauyne.
Helvin.
Iridium.
Irite.
Iron.
Iserine.
Kerate (muriate of silver).
Lead.
Linnéite (sulphuret of cobalt).
Magnetite (magnetic iron ore).
Mercury.
Palladium.
Pechuran (pitch blende).
Percylite.
Periclase.
Perowskite.
Pharmacosiderite (arseniate of iron).
Pyrite (sulphuret of iron).
Pyrochlore.
Rammelsbergite (white arsenical nickel).
Rhodizite.
Safflorite (arsenical cobalt).
Sal ammoniac.
Salt.
Senarmontite.
Silver.
Skutterudite.
Smaltine (tin white cobalt).
Spinelle.
Steinmannite.
Sylvine.
Tennantite.
Tritonite.
Ullmanite (sulphuret of nickel and antimony).
Uwarrowite.
Voltaite.

Minerals whose crystals cleave parallel to the faces of the Octahedron:—

Alum.
Arsenite.
Boracite.
Bornite.
Chromite.
Cuprite.
Diamond.
Eisennickelkies.
Fahlerz.
Fluor
Franklinite.
Gahnite.
Grünauite.
Magnetite.
Sal ammoniac.
Senarmontite.
Smaltine.
Spinelle.

Rhombic Dodecahedron.—The rhombic dodecahedron is a solid, bounded by twelve equal and similar four-sided figures, called *rhombs*. A *rhomb* is a figure such as $O_1\ P_2\ O_5\ P_5$ (Fig. 26), which has all its sides equal, the angle at O_1 being equal to that at O_5, and that at P_2 to the angle at P_5. This form is sometimes called the *granatoëdron*, because it is a characteristic form of the *garnet*. The rhombic dodecahedron has *twenty-four equal edges*, $P_1\ O_1$, $P_1\ O_4$, &c., *six four-faced solid angles*, $P_1\ P_2$, &c., P_6, and *eight three-faced solid angles*, $O_1\ O_2$, &c., O_8. Each face is inclined to its adjacent faces at an angle of 160°; the great angle of the rhombic face as $P_2\ O_1\ P_5$, is 109° 28′, and the smaller angle, as $O_1\ P_5\ O_5$, is 70° 32′.

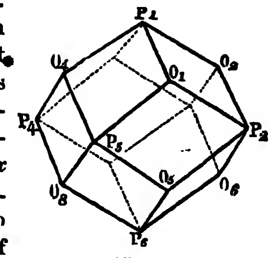


Fig. 26.

To draw the Rhombic Dodecahedron.—Describe a cube $A_1\ A_2\ A_3$ &c., A_8, (Fig. 27). Join $A_1\ A_7$, $A_2\ A_8$, &c., meeting in C.

Find P_1 the centre of the face $A_1\ A_2\ A_3\ A_4$. Join CP_1 and $P_1\ A_1$.

Bisect $A_1\ B_5$ in E. Through E draw ED parallel to $P_1\ A_1$, and cutting CA_1 in O_1.

Through O_1 draw $O_1\ O_2$ parallel to $A_1\ A_2$, cutting CA_2 in O_2, $O_2\ O_3$ parallel to $A_2\ A_3$, and $O_3\ O_4$ parallel to $A_3\ A_4$.

Also, through O_1 draw $O_1\ O_5$ parallel to $A_1\ A_5$, cutting CA_5 in O_5; draw $O_5\ O_6$, $O_6\ O_7$, and $O_7\ O_8$ parallel to $A_5\ A_6$, $A_6\ A_7$, and $A_7\ A_8$.

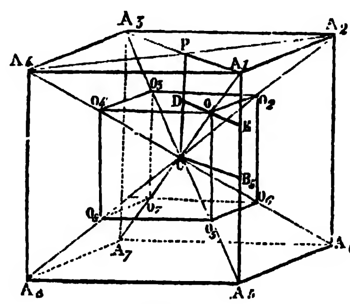


Fig. 27.

$O_1\ O_2$ &c. O_8, will be the eight solid angles of a cube inserted in the cube $A_1\ A_2$ &c. A_8, with the same centre, and having its edges half the length of the edges of $A_1\ A_2$ &c. A_8.

$P_1\ P_2$, &c., P_6 (Fig. 28, which are not marked on Fig. 27, to avoid crowding the figure), will be the six points where the six four-faced solid angles of the rhombic dodecahedron, inscribed in the cube $A_1\ A_2$, &c., A_8, will touch its faces.

$O_1\ O_2$, &c., O_8, the eight points where the octahedral axes of the cube pass through the eight three-faced solid angles of the inscribed rhombic dodecahedron.

Joining the lines $P_1\ O_1$, $O_1\ P_2$, $O_1\ P_5$, &c., as shown in Fig. 29, the rhombic dodecahedron will be represented in perspective.

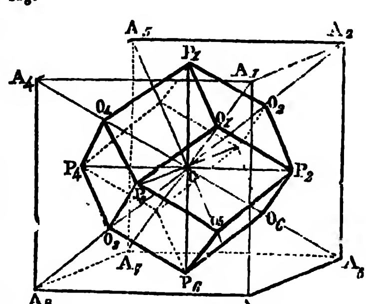


Fig. 28.

If the opposite angles of each face be joined, such as $O_1\ O_2$, $P_1\ P_2$, the rhombic axes of the cube will be found to pass through the intersection of these lines, and will also be perpendicular to the face through which they pass. The cubical axes of the rhombic dodecahedron are equal to the cubical axes of the cube, and join the opposite four-faced solid angles.

The octahedral axes of the rhombic dodecahedron are one-half the octahedral axes of the cube, and join the opposite three-faced solid angles.

The rhombic axes are half the rhombic axes of the cube in which it is inscribed, and join the centres of the opposite faces.

Symbols of the Rhombic Dodecahedron.—Each face of the rhombic dodecahedron cuts two of the cubical axes at equal distances from its centre, and the other at an infinite distance, or is parallel to it. Thus the face, $P_1\,O_1\,P_2\,O_2$ cuts the axis CP_1 in P_1, and CP_2 in P_2, and is parallel to the axis CP_3. The symbol of the rhombic dodecahedron, which represents this relation of all it faces to the rectangular axes, is $1\,1\,\infty$. Naumann's symbol is ∞ O, Miller's 110, and Brooke and Levy's modification of Haüy, B^1 or b^1.

To describe the net of a Rhombic Dodecahedron which may be inscribed in a given cube.—Describe a square, $P_1\,B_1\,P_2C$, having its side equal to half the edge of the given cube. Join B_1 C, and $P_1\,P_2$ meeting in R_1. Produce $B_1\,P_1$ to A_1, and P_2 C to B_5. Make $P_1\,A_1$, and CB_5, equal to CB_1, and CR_5 equal to CR_1.

Join CA_1. Bisect $A_1\,B_5$ in E. Through E draw EO_1D parallel to $A_1\,P_1$, cutting A_1C in O_1. Join $P_1\,O_1$, $O_1\,R_5$.

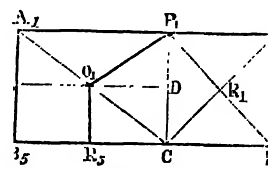


Fig. 29.

$P_1\,A_1\,B_5C$ represents the fourth part of the section of the cube, with its inscribed rhombic dodecahedron, through the lines $A_1\,A_3\,A_7\,A_5$ (Fig. 28), and $P_1\,B_1\,P_2C$, the fourth part of the section, through the lines joining the points $B_1\,B_3\,B_{11}\,B_9$ (Fig. 18) of the cube.

To describe the face of the Rhombic Dodecahedron.—Draw a line, $P_1\,P_2$ (Fig. 30), equal $P_1\,P_2$ of Fig. 29. On it describe an isosceles triangle, having its sides $P_1\,O_1$, $P_2\,O_1$, equal $P_1\,O_1$ of Fig. 29. Make a similar triangle P_1, O_2 P_2 on the other side of $P_1\,P_2$. Then P_1 O_2 P_2 O_1 is the face of the rhombic dodecahedron, which may be inscribed in a cube whose edge is twice the length of $P_1\,B_1$, or P_2 C of Fig. 29. Twelve of these rhombs, arranged as in Fig. 31, will give the required net of the rhombic dodecahedron.

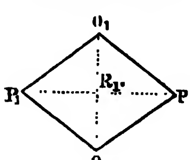


Fig. 30.

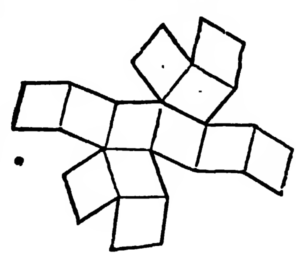


Fig. 31.

Minerals whose crystals occur in the form of the rhombic dodecahedron, or whose modifications present faces parallel to it:—

Alabandine (sulphate of magnesia.
Alum.
Amalgam.
Argentite (sulphuret of silver).
Blende (sulphuret of zinc.)
Boracite.
Bornite (purple copper).
Cuprite (red oxide of copper).
Diamond.
Dufrenoysite.
Eulytine (bismuth blende).
Fahlerz (gray copper).
Fluor.
Franklinite.
Galena (sulphuret of lead.)
Garnet.
Gold.
Hauerite.
Hauyne.
Iserine.

Ittnerite.
Kerate (muriate of silver).
Leucite.
Magnetite (magnetic iron ore).
Percylite.
Perowskite.
Pharmacosiderite.
Pyrite (sulphuret of iron).
Pyrochlore.
Rammelsbergite (white arsenical nickel).
Rhodizite.
Sal ammoniac.
Salt.
Silver.
Skutterudite.
Smaltine (tin white cobalt).
Sodalite.
Spinelle.
Stannine (sulphuret of tin).
Tennantite.
Ullmanite (sulphuret of nickel and antimony.)
Voltaite.

Minerals whose crystals cleave parallel to the faces of the rhombic dodecahedron :—

Alabandine.
Amalgam.
Argentite.
Blende.
Eulytine.
Garnet.
Hauyne.
Ittnerite.
Leucite.
Skutterudite.
Smaltine.
Sodalite.
Stannine.
Tennantite.

The cube, octahedron, and rhombic dodecahedron, are the only forms parallel to which cleavages have been observed in crystals belonging to the cubical system.

Three-Faced Octahedron.—This figure, called also the *triakisoctahedron*, and by Haidinger, *galenoid*, as a characteristic form of *galena*, is a solid bounded by twenty-four isosceles triangles.

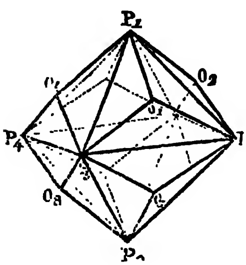


Fig. 32.

Solid Angles.—It has six eight-faced solid angles, P_1 P_2, &c., P_6; and eight three-faced solid angles, O_1 O_2, &c., O_8.

Edges.—There are twelve longer edges joining the eight-faced solid angles, P_1 P_5, P_5 P_2, P_5 P_1, &c., and twenty-four shorter edges joining each three-faced solid angle to three of the eight-faced solid angles, O_1 P_5, O_1 P_2, O_1 P_1, &c.

An infinite number of varieties of this solid might exist; only seven different species have been observed in the mineral kingdom. The forms vary from that of the octahedron to the rhombic dodecahedron.

If a triangular pyramid, whose base is an equilateral triangle, and each of its faces an isosceles triangle, be applied to each face of a regular octahedron, the resulting form would be a three-faced octahedron. For every variation in height of this triangular pyramid as we may conceive it increasing in altitude, from the surface of the octahedron till it arrived at such a height that two adjacent triangular faces, such as P_1 O_1 P_5, and P_1 O_4 P_5, should lie in the same plane, when the figure would become a rhombic dodecahedron, we should have a distinct three-faced octahedron. When the three-faced octahedron is inscribed in the cube, the eight-faced solid angles touch the centre of each face of the cube, and the three-faced solid angles always lie in its octahedral axes.

Symbols of the Three-faced Octahedron.—Every face of this solid cuts two of the cubical axes passing through its centre, at a distance equal to that of its eight-faced solid angle from the centre, and the third axis produced at a greater distance. If the shorter distance be represented by 1, and the greater by n, where n may be any number or fraction greater than 1; $11n$ will be the symbol for the three-faced octahedron.

Naumann's symbol is nO; Miller's hhk, h being greater than k; and Brooke and Levy's modification of Haüy $A^{\frac{1}{n}}$ or $a^{\frac{1}{n}}$.

To draw the Three-faced Octahedron.—Let the figure be that whose symbol is $11n$. Describe a cube, $A_1\ A_2\ A_3$ &c., A_8 (Fig. 33). Let P_1 be the centre of the face $A_1\ A_2\ A_3\ A_4$; B_5 the centre of the edge $A_1\ A_5$. Take B_5 E equal the $\frac{n}{2n+1}$th part of $B_5\ A_1$; that is if $n = 2$, as in the accompanying figure (Fig. 33), take B_5 E $= \frac{2}{5}$th of $B_5\ A_1$. Through E draw E D, parallel to $A_1\ P_1$, cutting A_1 C in O_1. Through O_1 draw $O_1\ O_2$ parallel to $A_1\ A_2$, $O_2\ O_3$ parallel to $A_2\ A_3$, &c., as in the preceding figure 27.

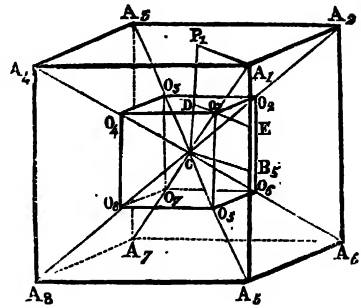


Fig. 33.

$O_1\ O_2\ O_3$ &c., O_8 will be the cube whose centre coincides with that of $A_1\ A_2$, &c., A_8, and has its edge $O_1\ O_5 = \frac{n}{2n+1}$th part of the edge $A_1\ A_5$, $O_1\ O_2$, &c., O_8 will be the points where the octahedral axes pass through the three-faced solid angles of the three-faced octahedron inscribed in the cube. Joining $P_1\ O_1$, $P_2\ O_1$, $P_5\ O_1$, $P_1\ P_2$, &c., as in Fig. 34, the three-faced-octahedron will be drawn inscribed in the cube.

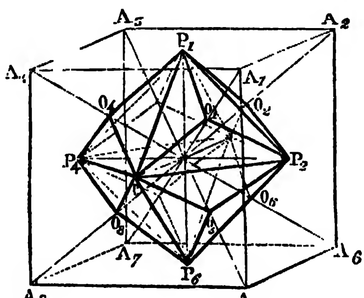


Fig. 34.

Axes.—The cubical axes of the three-faced octahedron are equal to those of the cube in which it is inscribed, and they join the opposite eight-faced solid angles.

The octahedral axes are $\frac{n}{2n+1}$th part of the octahedral axes of the cube, and join the opposite three-faced solid angles; and, as in the case of the octahedron, the rhombic axes are the half of the rhombic axes of the cube, and join the centres of the opposite longer edges.

As n varies from 1 when the three-faced octahedron coincides with the octahedron to ∞ when it coincides with the rhombic dodecahedron, the octahedral axes vary from the $\frac{1}{3}$rd to the $\frac{1}{2}$ of the octahedral axes of the cube, or the distance of the point O from C varies from the $\frac{1}{3}$rd to the $\frac{1}{2}$ of CA_1.

Inclination of the Faces of the Three-faced Octahedron.—If θ be the angle of inclination of any two adjacent faces, measured across the longer edge PP, then $\cos.\ \theta = \frac{2n^2 - 1}{2n^2 + 1}$, and if ϕ be the angle of two adjacent faces, measured across the shorter edge OP, $\cos.\ \phi = \frac{n\ (n+2)}{2n^2+1}$.

To describe a Net for the Three-faced Octahedron which may be inscribed in a given cube.—Describe a square, $P_1\ B_1\ P_2$ C (Fig. 35), having its sides equal to half the edge of the given cube. Join $P_1\ P_2$, and B_1 C meeting in R_1. Produce $B_1\ P_1$ to A_1, and P_2 C to B_5; make $A_1\ P_1$ and B_5 C both equal to B_1 C. In

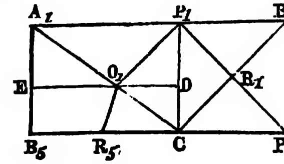


Fig. 35.

C B_3 make C R_3 equal to C R_1, join A_1 C. Take CD equal to $\frac{n}{2n+1}$th part of CP_1, and through D draw DE, parallel to A_1P_1, cutting A_1C in O_1. Join P_1O_1, O_1R_5.

Take P_1 P_2 (Fig. 36), equal P_1 P_2 of Fig. 35, and on it, as a base, describe an isosceles triangle, P_1 O_1 P_2 having its sides P_1 O_1, P_2, O_1, equal to P_1 O_1 of Fig. 35.

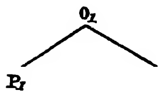
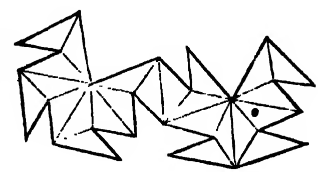


Fig. 36.

P_1 O_1 P_2 will be the face of the three-faced octahedron, which may be inscribed in the given cube. And twenty-four of these isosceles triangles, arranged as in Fig. 37, will form a net from which its model may be constructed.

Forms of three-faced Octahedron.—The three-faced octahedron, whose symbol is 112, 2 O of Naumann, 122 of Miller, and $a^{\frac{1}{2}}$ of Brooke and Levy, has its cubical axes equal those of the cube in which it is inscribed, its octahedral axes the $\frac{2}{5}$th, and its rhombic axes half those of the cube. Inclination of faces over shorter edge, 152° 44′, that of their normals 27° 16′; over the longer edge, 141° 3′, that of their normals, 38° 57′.



Fig

The following minerals present faces parallel to this form:—

Amalgam.	Fluor.	Pharmacosiderite
Argentite.	Franklinite.	Pyrite.
Blende.	Galena.	Skutterudite.
Cuprite.	Magnetite.	Spinelle.
Diamond.	Perowskite.	

The form 113, 3 O of Naumann, 133 of Miller, and $a^{\frac{1}{3}}$ of Brooke and Levy, has its octahedral axis equal $\frac{3}{7}$ths of those of the cube in which it is inscribed. Inclination of its faces over shorter edge, 142° 8′, that of their normals 37° 52′; over the longer edge 153° 28′, that of their normals, 26° 32′. Cuprite, Fluor, and Galena, are the only minerals which present faces of this form.

The form 11$\frac{3}{2}$, $\frac{3}{2}$O of Naumann, 233 of Miller, and $a^{\frac{2}{3}}$ of Brooke and Levy, has its octahedral axes equal $\frac{3}{8}$ths of those of the cube in which it is inscribed. Inclination of faces over shorter edge, 162° 40′, that of their normals, 17° 20′; over the longer edge, 129° 31′, that of their normals, 50° 29′.

Faces of this form occur in Fahlerz and Garnet.

The form 114, 4 O of Naumann, 144 of Miller, and $a^{\frac{1}{4}}$ of Brooke and Levy. Octahedral axes $\frac{4}{9}$ths of those of the cube. Inclination of faces over shorter edge, 136° 39′; their normals, 43° 21′; over longer edge, 159° 57′, normals, 20° 3′.

Faces of this form have been observed in crystals of Galena and Kerate.

The form 11$\frac{7}{4}$, $\frac{7}{4}$O of Naumann, 477 of Miller, and $a^{\frac{4}{7}}$ of Brooke and Levy, has its octahedral axis equal $\frac{7}{18}$th of those of the cube. Inclination of faces over shorter edge, 157° 5′, normals, 22° 55′; over longer edge, 136° 00, normals, 44°. Faces of this form have been observed on crystals of Galena.

The form 11$\frac{5}{4}$, $\frac{5}{4}$O of Naumann, 455 of Miller, and $a^{\frac{4}{5}}$ of Brooke and Levy, has its octahedral axis $\frac{5}{14}$ths of those of the cube. Inclination of faces over shorter edge, 170° 1′,

normals, 9° 59′; over the longer edge 121° 00′, normals, 59° 00′. This form occurs in Galena.

The form $11\frac{6}{6}\frac{5}{4}$, $\frac{6}{6}\frac{5}{4}O$ of Naumann, 64, 65, 65 of Miller, and $a\frac{6}{6}\frac{4}{5}$ of Brooke and Levy, has its octahedral axes $\frac{65}{194}$th of those of the cube. Inclination of faces over shorter edge, 179° 17′, normals, 0° 43′; over longer edge, 110° 18′, normals, 69° 42′. This three-faced octahedron approximates very closely to the octahedron, and has only been observed on some crystals of Alum.

The Twenty-four Faced Trapezohedron.—This form is called the twenty-four-faced trapezohedron, or deltohedron, because it has twenty-four faces, each of the form of the figure called a deltoid or trapezium. It is known also by the names of the *icositessarahedron;* and being a characteristic crystal of the mineral leucite, it has been called *leucitoid.*

Faces.—This form is bounded by twenty-four equal and similar deltoids, or trapeziums, such as the figure $P_1 R_4 O_1 R_1$, which has the sides $P_1 R_4$ equal $P_1 R_1$, and $R_4 O_1 = R_1 O_1$, the angle $P_1 R_4 O = $ angle $P_1 R_1 O_1$, but the angle $R_4 P_1 R_1$ not equal to the angle $R_4 O_1 P_1$.

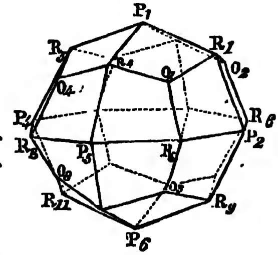


Fig. 38.

Solid Angles.—It has six four-faced solid angles, $P_1 P_2$, &c., P_6, which touch the centres of the faces of the cube in which it is inscribed, at the extremities of the cubical axes.

Twelve four-faced solid angles $R_1 R_2$, &c., R_{12}, which always lie in the rhombic axes of the cube in which it is inscribed. Eight three-faced solid angles, O_1 O_2, &c., O_8, which are always the octahedral axes of the cube in which it is inscribed.

Edges.—The edges are twenty-four longer, joining the four-faced solid angles, which terminate the cubical and rhombic axes, such as $P_1 R_1$, $P_1 R_2$, $P_1 R_3$, &c., and twenty-four shorter, joining the four-faced solid angles which terminate the rhombic axes to the three-faced solid angles which terminate the octahedral axes, as $O_1 R_1$, $O_1 R_1$, $O_1 R_3$, &c.

Symbols.—Every face of this form cuts one of the cubical axes at a distance from its centre, equal CP, and the other two axes produced at equal distances greater than CP.

Taking the lesser distance as 1, and the other two as *m*, where *m* may be any whole number or fraction greater than unity, the symbol which expresses this relation of the faces to the cubical axes will be 1*mm*. Naumann's symbol is *m*O*m*; Miller's *hhk*, *h* being less than *k*; Brooke and Levy's modification of Haüy, A^m or a^m, where *m* is greater than 1.

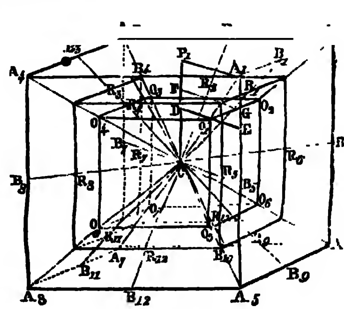


Fig. 39.

To Draw the Figure.—Describe a cube A_1 A_2, &c., A_7 (Fig. 39), with its cubical axes CP_1, CP_2, &c.; octahedral axes CA_1, CA_2, &c., and rhombic axes CB_1 CB_2, &c., CB_{12}.

Take E in $B_5 A_1$, so that $B_5 E = \frac{}{m+}$th part of $B_5 A_1$; and G, such that $B_5 G = \frac{m}{m+1}$th part of $B_5 A_1$.

Thus if $m = 2$ $B_5 E = \frac{2}{4}$ or $\frac{1}{2}$ of $B_5 A_1$, and $B_5 G = \frac{2}{3}$ of $B_5 A_1$, if $m = 3$ $B_5 E = \frac{3}{5}$ of $B_5 A_1$, and $B_5 G = \frac{3}{4}$ of $B_5 A_1$.

In CP_1 take $CD = B_5 E$, and $CF = B_5 G$. Join FG and DE, the latter cutting CA_1 in O_1.

Through O_1 draw $O_1 O_2$ parallel to $A_1 A_2$, cutting CA_2 in O_2, $O_2 A_3$ parallel to $A_2 A_3$, cutting CA_3 in O_3, and so on till a cube $O_1 O_2$, &c., O_8, is inscribed in the cube $A_1 A_2$, &c., A_8 with its edges parallel to it.

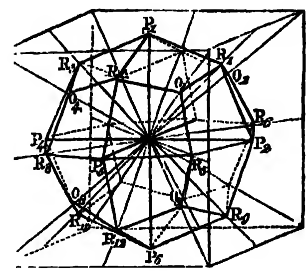


Fig. 40.

Through the point where FG cuts CA_1, draw lines parallel to $A_1 A_2$, and $A_1 A_4$ to meet CA_2 and CA_4, and complete the cube, of which these two lines will be edges.

Let $R_1 R_2$, &c., R_{12}, be the points where the lines CB_1, CB_2, &c., CB_{12}, cut the edges of this cube.

Now join the points PR and O as shown in Fig. 40, and the resulting form will be a representation of the twenty-four-faced trapezohedron inscribed in a cube.

Axes.—The cubical axes of this trapezohedron coincide with those of the cube in which it is inscribed, and join the opposite four-faced solid angles, $P_1 P_2$, &c., P_6. The octahedral axes are the $\frac{m}{m+2}$th part of those of the cube, and join the opposite three-faced angles $O_1 O_2$, &c., O_8.

The rhombic axes are the $\frac{m}{m+1}$th part of those of the cube, and join the opposite four-faced angles $R_1 R_2$, &c., R_{12}.

Inclination of Adjacent Faces—If θ be the angle of inclination of two adjacent faces, measured over the edge PR, joining the extremities of the rhombic and cubical axes, $\cos. \theta = \frac{m^2}{m^2 + 2}$; and if ϕ be the angle of inclination measured over the edge OR, joining the extremities of the rhombic and octahedral axes, $\cos. \phi = \frac{2m+1}{m^2+2}$.

Limits of the Form.—This form varies as m increases from 1 to an infinitely great number, from that of the octahedron to that of the cube. In this case θ increases from 109° 28′ to 180°, and ϕ decreases from 180° to 90°; the octahedral axes from the $\frac{1}{3}$rd to the whole, and the rhombic from the $\frac{1}{2}$ to the whole of the corresponding axes of the cube, in which the figure can be inscribed.

To construct a Net of twenty-four-faced Trapezohedron, which can be inscribed in a given Cube.—Describe a square $P_1 B_1 P_2 C$ (Fig. 41), having one of its sides equal half the edge of the given cube. Join CB_1, produce $P_2 C$, and $B_1 P_1$ to B_5 and A_1.

Make CB_5 and $P_1 A_1$ equal CB_1. Join $A_1 B_5$ and CA_1 Take $CD = \frac{m}{m+2} CP_1$, $CF = \frac{m}{m+1} CP_1$.

Draw DE and FG parallel to $A_1 B_1$.

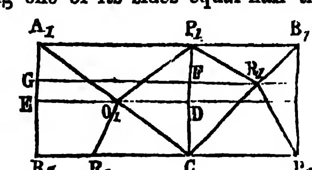


Fig. 41.

Let O_1 be the point where ED cuts A_1 C_1, and R_1 the point where FG cuts CB.

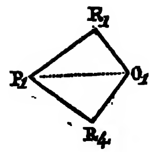


Fig. 42.

Take CR_5 in CB_5 equal to CR_1. Join P_1 R_1, R_1 P_2, P_1 O_1 and O_1 R_5.

Draw a line P_1 O_1 (Fig. 42), equal P_1 O_1 of Fig. 41, and on it describe a triangle having its sides P_1 R_1 and O_1 R_1 equal to P_1 R_1, and O_1 R_5 of Fig. 41. Describe a similar and equal triangle P_1 R_4 O_1 on the other side of P_1 O_1.

Then P_1 R_1 O_1 R_4 will be a face of the required twenty-four faced trapezohedron; and twenty-four of these being arranged as in Fig. 43, will form the net.

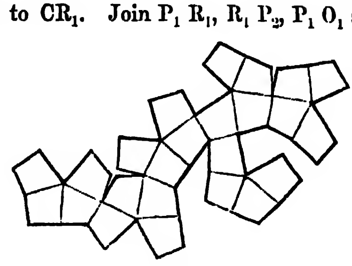


Fig. 43.

Forms of the Twenty-four faced Trapezohedron.—The form 122, 2 O 2 of Naumann, 112 of Miller, and a^2 of Brooke and Levy, has its octahedral axes $\frac{1}{2}$, and its rhombic axes $\frac{2}{3}$ of the corresponding axes of the cube in which it can be inscribed. Inclination of faces over any edge PR, 131° 49′, of their normals 48° 11′; over any edge OR 146° 27′, normals 33° 33′.

Crystals of the following minerals have faces parallel to this form:—

Amalgam.	Fahlerz.	Pyrite.
Argentite.	Franklinite	Pyrochlore.
Analcime.	Fluor.	Sal ammoniac.
Boracite.	Gold.	Sodalite.
Cuprite.	Galena.	Smaltine.
Dufrenoysite.	Garnet.	Tennantite.
Eulytine.	Leucite.	

The form 133, 3 O 3 of Naumann, 113 of Miller, and a^3 of Brooke and Levy, has its octahedral axes $\frac{1}{3}$, and rhombic $\frac{3}{4}$ of those of the cube. Inclination over PR 144° 54′ normals, 35° 6′; over OR 129° 31′, normals 50° 29′. It occurs in

Blende.	Gold.	Perowskite.
Copper.	Galena.	Pyrochlore.
Fahlerz.	Magnetite.	Spinelle.
Fluor.	Pyrite.	

The form 1 $\frac{3}{2}$ $\frac{3}{2}$, $\frac{3}{2}$ O $\frac{3}{2}$, of Naumann, 223 of Miller, and $a^{\frac{3}{2}}$ of Brooke and Levy; octahedral axes $\frac{3}{7}$, rhombic $\frac{3}{5}$. Inclination over PR 121° 58′, normals 58° 2′; over OR 160° 15′, normals 19° 45′. It occurs in

Argentite, Gold, and Tennantite.

The form 1 $\frac{4}{3}$ $\frac{4}{3}$, $\frac{4}{3}$ O $\frac{4}{3}$ Naumann. 334 Miller, and $a^{\frac{4}{3}}$ Brooke and Levy, octahedral axes $\frac{2}{5}$, rhombic $\frac{4}{7}$. Inclination over PR 118° 4′, normals 61° 56′, over OR 166° 4′, normals 13° 56′. Occurs in Galena.

The form 1 $\frac{9}{4}$ $\frac{9}{4}$, $\frac{9}{4}$ O $\frac{9}{4}$ Naumann, 449 Miller, and $a^{\frac{9}{4}}$ Brooke and Levy, octahedral axes $\frac{9}{17}$, rhombic $\frac{9}{13}$. Inclination over PR 137° 48′, normals 44° 12′, over OR 141° 9′, normals 38° 51′. Occurs in Perowskite.

The form 1 $\frac{8}{3}$ $\frac{8}{3}$, $\frac{8}{3}$ O $\frac{8}{3}$ Naumann, 338 Miller, $a^{\frac{8}{3}}$ Brooke and Levy, octahedral axes $\frac{4}{7}$, rhombic $\frac{8}{11}$. Inclination over PR 141° 18′, normals 38° 42′; over OR 134° 2′, normals 45° 58′. Occurs in Fluor.

The forms 144, 1 10 10, 1 12 12, 1 16 16, and 1 40 40, whose octahedral axes are respectively $\frac{2}{3}$, $\frac{5}{6}$, $\frac{6}{7}$, $\frac{8}{9}$, and $\frac{20}{21}$, of those of the cube in which they are inscribed, and

rhombic axes the $\frac{4}{3}$, $\frac{10}{11}$, $\frac{12}{13}$, $\frac{16}{17}$, and $\frac{40}{41}$. Their respective inclinations over PR being 152° 44′, 168° 38′, 172° 52′, and 177° 8′; over OR 120° 00′, 101° 53′, 99° 52′, 97° 21′, and 92° 54′, those of the normals of the former being 27° 16′, 11° 22′, 9° 30′, 7° 8′, and 2° 52′; of the latter 60° 00′, 78° 7′, 80° 8′, 82° 39′, and 87° 6′. 144 occurs in Kerate, 1 10 10, and 1 16 16 in Magnetite, 1 12 12 in Blende, and 1 40 40 in Pharmacosiderite.

The Four-Faced Cube, called also the *pyramidal cube* and *tetrakis-hexahedron.* Being a characteristic form of fluor spar, Haidinger gave it the name of *Fluoride.*

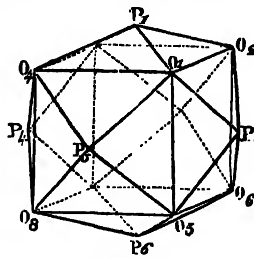


Fig. 44.

Faces.—This form is bounded by twenty-four equal and similar isosceles triangles. As the three-faced octahedron may be derived from the octahedron by placing on every face of the octahedron a pyramid with three triangular faces on a triangular base equal to the face of the octahedron, so this form may be derived from the cube by placing on every face of the cube a pyramid with four isosceles triangles for its faces, on a square base equal to the face of the cube.

Solid Angles.—It has six four-faced solid angles, P_1 P_2, &c., P_6, which touch the centres of the faces of the cube in which it is inscribed, at the extremities of the cubical axes.

Eight six-faced solid angles, O_1 O_2, &c., O_8, which always lie in the octahedral axes of the cube in which it is inscribed.

Edges.—There are twelve longer equal edges (O_1 O_2, O_2 O_6, &c.) joining the six-faced solid angles together, and twenty-four shorter equal edges, P_1 O_1, P_1 O_2, &c., joining the four-faced solid angles with the six-faced ones.

Symbols.—Every face of this form cuts one of the cubical axes at a distance, CP (Fig. 45), from its centre, another axis at a distance m times CP from the centre, and is parallel to the third axis; m may be any whole number or any fraction greater than one. Taking CP = 1, the symbol which will represent this relation is 1 m ∞. Naumann's symbol is ∞Om, Miller's *hko*, and Brooke and Levy's modification of Hauy, b^m or B^n

To draw the Four-faced Cube.—Describe a cube A_1 A_2, &c., A_8 (Fig. 45), with its octahedral axes A_1 A_7, A_2 A_8, &c., meeting in C, and its rhombic axes B_1 B_{11}, B_3 B_9, &c.

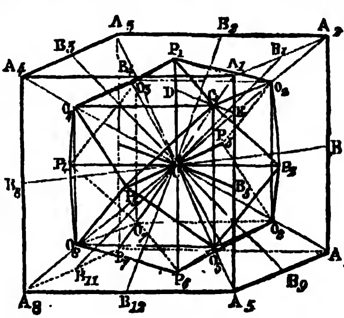


Fig. 45.

Take E in B_5 A_1, so that $B_5 E = \frac{m}{m+1} CA_1$.

Thus, if $m = 2$ $B_5E = \frac{2}{3} CA_1$.

Thus, if $m = 3$ $B_5E = \frac{3}{4}$ CA.

In CP_1 take $CD = B_5 E$. Join DE, cutting CA_1 in O_1.

Through O_1 draw O_1 O_2 parallel to A_1 A_2, cutting CA_2 in O_2. Through O_2 draw O_2 O_3 parallel to A_2 A_3, cutting CA_3 in O_3; and so on, till a cube O_1 O_2, &c., O_8, is inscribed in the cube A_1 A_2, &c., A_8, with its edges parallel to it.

Join the points P_1 O_1, P_1 O_2, &c., as in Fig. 45, and the resulting figure will be a representation of the four-faced cube inscribed in a cube.

Axes.—The cubical axes, P_1 P_6, P_2 P_4, and P_5 P_3 of the four-faced cube coincide

with those of the cube in which it is inscribed, and join the opposite four-faced solid angles, P_1 P_2, &c., P_6.

The octahedral axes are the $\frac{m}{m+1}$th part of those of the cube, and join the opposite six-faced solid angles, O_1 O_2, &c., O_8.

The rhombic axes are the $\frac{m}{m+1}$th part of those of the cube, and join the centres of the opposite longer edges, O_1 O_2, O_8 O_7, &c.

Inclination of Adjacent Faces.—If θ be the angle of inclination of two adjacent faces, measured over the edge, joining the extremities of the octahedral axes, such as O_1 O_2, $\cos.\ \theta = \frac{2m}{1+m^2}$; and if ϕ be the angle of inclination measured over the edge joining the extremities of the octahedral axes with those of the cubical, such as P_1 O_1, then $\cos.\ \phi = \frac{m^2}{1+m^2}$.

Limits of the Form.—The four-faced cube varies as m increases in magnitude, from 1 to ∞, from the rhombic dodecahedron to the cube. In this case θ decreases from 180° to 90°, and ϕ increases from 120° to 180°. The octahedral and rhombic axes increase from the $\frac{1}{2}$ to the whole of the corresponding axes of the cube in which the figure can be inscribed.

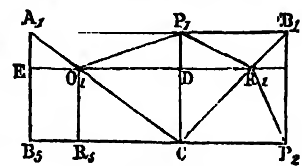


Fig. 46.

To construct a Net of the four-faced Cube which can be inscribed in a given Cube.

Describe a square, P_1 B_1, P_2 C (Fig. 46), having one of its sides equal half the edge of the given cube.

Join CB_1. Produce P_2 C, and B_1 P_1 to B_5 and A_1. Make CB_5 and P_1 A_1 both equal CB_1.

Join A_1 B_5, and A_1 C.

Take $B_5E = \frac{m}{m+1}$ A_1 B_5.

Through E draw ED parallel A_1 P_1, cutting A_1 C in O_1. Join P_1 O_1.

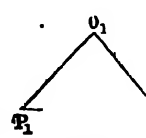


Fig. 47.

Draw a line, P_1 P_2 (Fig. 47), equal CB_1, or P_1 P_2 of Fig. 46. On this base describe an isosceles triangle O_1 P_1 P_2, having each of its sides, P_1 O_1, O_1 P_2, equal P_1 O_1 of Fig. 46.

P_1 O_1 P_2 will be a face of the required four-faced cube; twenty-four of these faces being arranged together, as in Fig. 48, will form the required net.

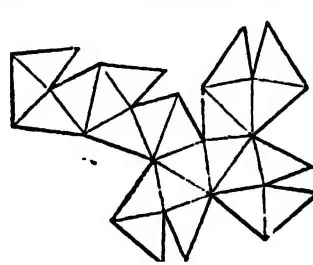


Fig. 48.

Forms of the four-faced cube.

The form 12∞, $\infty O2$ of Naumann, 210 Miller, and b^2 of Brooke and Levy, has its octahedral and rhombic axes $\frac{2}{3}$ of those of the cube in which it is inscribed. Inclination of faces over any edge, such as O_1 O_2 143° 8′ of their normals 36° 52′; over any edge, such as P_1 O_1 143° 8′ normals 36° 52′.

Crystals of the following minerals have faces parallel to this form:—

Argentite.	Fluor.	Garnet.	Percylite.
Copper.	Gold.	Magnetite.	Salt.
Cobaltine.	Gersdorffite.	Pyrite.	Silver.
Cuprite.			

The form 13∞, ∞O3 Naumann, 310 Miller, b^3 Brooke and Levy, has its octahedral and rhombic axes $\frac{3}{4}$ of the cube; inclination over O_1O_2 126° 52′, normals 53° 8′; over P_1O_1 154° 9′, normals 25° 51′. It occurs in

Amalgam, Fahlerz, Fluor, Hauerite, and Pyrite.

The form $1\frac{3}{2}$∞, ∞O$\frac{3}{2}$ Naumann, 320 Miller, $b^{\frac{3}{2}}$ Brooke and Levy, has its octahedral and rhombic axes $\frac{3}{5}$ of the cube, inclination over O_1O_2 157° 23′, normals 22° 37′; over P_1O_1 133° 19′, normals 46° 11′. It occurs in

Argentite, Blende, Diamond, Pyrite, and Perowskite.

The form $1\frac{5}{2}$∞, ∞ O$\frac{5}{2}$ Naumann, 520 Miller, $b^{\frac{5}{2}}$ Brooke and Levy, has its octahedral and rhombic axes $\frac{4}{7}$th those of the cube, inclination over O_1O_2 133° 56′, normals 46° 24′; over P_1O_1 149° 33′, normals 30° 27′. It occurs in

Copper and Fluor.

The form $1\frac{4}{3}$∞, ∞ O$\frac{4}{3}$ Naumann, 130 Miller, and $b^{\frac{4}{3}}$ Brooke and Levy, has its octahedral and rhombic axes $\frac{4}{7}$th those of the cube, inclination over O_1O_2 163° 44′, normals 16° 16;′ over P_1O_1 129° 48′, normals 50° 12′. It occurs in

Diamond and Perowskite.

The form 14∞, ∞O4 Naumann, 110 Miller, and b^4 Brooke and Levy, has its octahedral and rhombic axes $\frac{4}{5}$ of the cube, inclination over O_1O_2 118° 4′, normals 61° 56′; over P_1O_1 160° 15′, normals 19° 45′. It occurs in

Cobaltine and Silver.

The form $1\frac{5}{4}$∞, ∞O$\frac{5}{4}$ Naumann, 510 Miller, $b^{\frac{5}{4}}$ Brooke and Levy, has its octahedral and rhombic axes $\frac{5}{9}$th of the cube, inclination over edge O_1O_2 167° 19′, normals 12° 41′; over edge P_1O_1 127° 34′, normals 52° 26′. It occurs in

Perowskite.

The form 15∞, ∞O5 Naumann, 510 Miller, b^5 Brooke and Levy, has its octahedral and rhombic axes $\frac{5}{6}$ of the cube, inclination over O_1O_2 112° 38′, normals 67° 42′, over P_1O_1 164° 4′, normals 25° 51′. It occurs in

Cuprite.

The form $1\frac{5}{4}$∞ approaches nearer to the rhombic dodecahedron, and the form 15∞ to the cube, than any of the other forms which have been described as occuring in nature.

Six-faced Octahedron.—The six-faced octahedron, called also the *hexakisoctahedron*, *tetra-kontaoktaëdron*, *pyramidal-granatohedron*, *triagonal polyhedron*. Being a characteristic form of the diamond, Haidinger named it *Adamantoid.*

Faces, Edges, and Solid Angles.—The six-faced octahedron is bounded by forty-eight equal and similar scalene triangles, such as $P_1 O_1 R_1$, $P_1 O_1 R_4$, &c. It has

six eight-faced solid angles, P_1 P_2, &c., P_6, whose apices terminate the cubic axes and touch the faces of the cube in which the figure can be inscribed. Eight six-faced solid angles, O_1 O_2, &c., O_8, whose apices always lie in the octahedral axes, and twelve four-faced solid angles, R_1 R_2 R_3, &c., R_{12}, whose apices always lie in the rhombic axes of the cube in which the six-faced octahedron can be inscribed. It has twenty-four long edges, P_1 O_1, P_1 O_2, &c., P_6 O_8, joining the apices of the eight-faced and six-faced solid angles, twenty-four intermediate edges, P_1 R_1, R_4 P_5, &c., joining the apices of the eight-faced and four-faced solid angles, and twenty-four short edges, O_1 R_1, O_1 R_1, O_1 R_3, &c., joining the apices of the six-faced and four-faced solid angles.

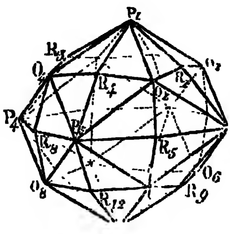


Fig. 49.

Symbols for the Six-faced Octahedron.—Every face of the six-faced octahedron, if produced, will cut three of the cubical axes produced in three points at unequal distances from the centre of the axes. Thus, in Figs. 49 or 50, the face O_1 R_5 P produced cuts the axis C P_2 at the point P_2, the axis C P_5 produced at a distance $\frac{3}{2}$ of C P_5, and C P_1 produced at a distance three times C P_1 from C, the centre of the axes and figure. Similarly, every face of the figure cuts one axis at a distance C P, another produced at $\frac{3}{2}$ of C P, and the third cubical axis produced at a distance three times C P. Taking C P, the distance of the centre of the figure from the apex of one of its eight-faced solid angles, as our unit, the symbol which will represent this relation of the faces to the cubical axes will be 1, $\frac{3}{2}$, 3. The general symbol will be 1, *m*, *n*, where *m* and *n* are any whole numbers or fractions greater than one, and *m* less than *n*.

Naumann's symbol is *m* O *n*, Miller's *h k l*, *h*, *k* and *l* being all three whole numbers; and Brooke and Levy's modification of Haüy, $B^{\frac{1}{h}}$ $B^{\frac{1}{k}}$ $B^{\frac{1}{l}}$ or $b^{\frac{1}{h}}$, $b^{\frac{1}{k}}$, $b^{\frac{1}{l}}$.

To draw the Six-faced Octahedron, whose symbol is 1, *m*, *n*.

Describe a cube A_1 A_2, &c., A_7 A_8 (Fig. 50) with its octahedral axes, C A_1, C A_2, &c. C A_8, rhombic axes C B_1, C B_2, &c. C B_{12}, and cubic axes C P_1, C P_2, &c. C P_6; only one of the latter, C P_1, is shown in Fig. 52, in order not to crowd the figure unnecessarily.

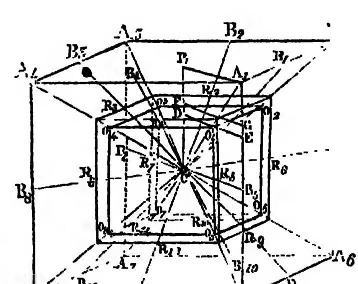


Fig. 50.

Take a point E in B_5 A_1, such that

$$B_5\,E = \frac{1}{1 + \frac{1}{m} + \frac{1}{n}}\,B_5\,A_1$$

For the form 1, $\frac{3}{2}$, 3 $B_5\,E = \frac{1}{1 + \frac{2}{3} + \frac{1}{3}}$ B_5 A_1 = $\frac{3}{6}$ B_5 A_1, or B_5 E = $\frac{1}{2}$ B_5 A_1.

Take another point G in B_5 A_1, such that

$$B_5\,G = \frac{1}{1 + \frac{1}{m}}\,B_5\,A_1.$$

For the form 1, $\frac{3}{2}$, 3 $B_5\,E = \frac{1}{1 + \frac{2}{3}}\,B_5\,A_1 = \frac{3}{5}\,B_5\,A_1$.

Join P_1 A_1 and C B_5; through E and G, draw E D, and E F parallel to A_1 P_1 or B_5 C. Let E D cut C A_1 in O_1. Through O_1 draw O_2 parallel to A_1 A_2, cutting C A_2

in O_2; $O_2 O_3$ parallel to $A_2 A_3$, cutting $C A_3$ in O_3, and so on, till a cube $O_1 O_2$, &c., O_8, is inscribed in $A_1 A_2$, &c., A_8; having $C O_1$ $C O_2$, &c., $C O_8$ for its octahedral axes.

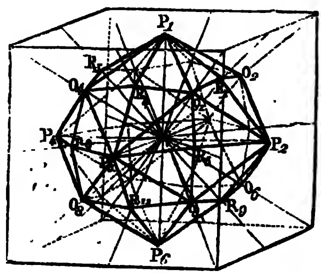


Fig. 51.

Similarly, commencing from the point where F G cuts $C A_1$, draw another cube whose edges are parallel to the one just described, and having $C R_1$, $C R_2$, $C R_3$, &c., $C R_{12}$ for its rhombic axes, as shown in Fig. 50. Join the points $P_1 O_1$, $O_1 R_4$, $P_1 R_4$, &c., as shown in Fig. 51, and the six-faced octahedron will be drawn, with all its axes inscribed in a cube. In this, as in the preceding forms, if it is only required to show the form itself, as in Fig. 49, the Figure 51 may be first drawn in pencil, and the outlines of the form being drawn in ink, the other lines may be rubbed out. The form drawn in Figs. 49 and 51 is that whose symbol is 1, $\frac{3}{2}$, 3, but the student is advised to draw for himself some of the other forms which occur in nature of the six-faced octahedron, in order to familiarise himself with the different properties of the figure, and its relations to the axes of the cube in which it is inscribed.

Axes of the Six-faced Octahedron.

The cubical axes of the six-faced octahedron join the opposite eight-faced solid angles, and are equal to the cubical axes of the cube in which it is inscribed.

The octahedral axes join the opposite six-faced solid angles, and are equal to the $\dfrac{1}{1+\frac{1}{m}+\frac{1}{n}}$ th part of the octahedral axes of the cube in which the figure is inscribed.

The rhombic axes join the opposite four-faced solid angles, and are equal to the $\dfrac{1}{1+\frac{1}{m}}$ th part of the rhombic axes of the cube in which the figure is inscribed.

Inclination of the Adjacent Faces.

If θ be the angle of inclination of two adjacent faces over the edge P O (Figs. 49 and 51), joining the eight-faced and six-faced solid angles,

$$\text{Cos. } \theta = \frac{1 + \frac{2}{m\,n}}{1 + \frac{1}{m^2} + \frac{1}{n^2}}.$$

If ϕ be the angle of inclination over the edge OR, joining the six-faced and four-faced solid angles,

$$\text{Cos. } \phi = \frac{\frac{2}{m} + \frac{1}{n^2}}{1 + \frac{1}{m^2} + \frac{1}{n^2}}.$$

If ψ be the angle of inclination over the edge RP, joining the four-faced and eight-faced solid angles,

$$\text{Cos. } \psi = \frac{1 + \frac{1}{m^2} - \frac{1}{n^2}}{1 + \frac{1}{m^2} + \frac{1}{n^2}}.$$

Limits of the Form of the Six-faced Octahedron.

The six-faced octahedron may be regarded as the most general form of the cubical system, and that from which all the others may be easily derived. Thus, as m and n approach in magnitude to unity, the *six-faced octahedron* approximates to the *octahedron;* and when m and n are both equal to unity, it becomes the *octahedron.* In this case, the six faces forming the six-faced solid angle all lie in the same plane, and the edges $P_1 R_4$ and $R_5 P_5$ lie in the same line.

As m and n both increase in magnitude and in equality to each other, the *six-faced octahedron* approximates to the *cube;* and when m and n are both infinitely great it becomes the *cube.* In this case, the eight planes which form each eight-faced solid angle all lie in the same plane, and the edges $O_1 R_4$ and $R_4 O_4$ lie in the same line.

As m approaches to unity while n increases in magnitude, the *six-faced octahedron* approximates to the *rhombic dodecahedron;* and when m equals unity, and n is infinitely great, it becomes the *rhombic dodecahedron.* In this case, the four planes which form each four-faced solid angle lie in the same plane.

When m equals unity while n remains finite, the *six-faced octahedron* becomes the *three-faced octahedron;* and the planes on each side of the edge RO lie in the same plane.

When m and n are equal to each other, both finite and greater than unity, the *six-faced octahedron* becomes the *twenty-four-faced trapezohedron;* and the planes on each side of the edge PO lie in the same plane.

When m remains finite, and n becomes infinite, the *six-faced octahedron* becomes the *four-faced cube,* and the planes on each side of the edge PR lie in the same plane.

All the formula for the axes and the inclination of the faces, &c., for all the holohedral forms of the cube may be derived from those of the six-faced octahedron, by substituting $\frac{1}{0}$ for m and n, for the cube; 1 for m and n for the octahedron; 1 for m and $\frac{1}{0}$ for n for the rhombic dodecahedron; 1 for m for the three-faced octahedron; m for n for the twenty-four-faced trapezohedron; and $\frac{1}{0}$ for n for the four-faced cube.

To describe a Net for the Six-faced Octahedron which may be inscribed in a given Cube.

Describe a square, $P_1 B_1 P_2 C$ (Fig. 52), having one of its sides half the edge of the given cube. Join CB_1.

Produce $B_1 P_1$ to A_1, and $P_2 C$ to B_5.

Make $A_1 P_1$ and $C B_5$ both equal $C B_1$. Join $A_1 B_5$ and $A_1 C$.

Take $B_5 E = \dfrac{1}{1 + \frac{1}{m} + \frac{1}{n}} B_5 A_1$ and $B_5 G = \dfrac{1}{1 + \frac{1}{m}} B_5 A_1$.

Through G and E draw G F and E D parallel to $A_1 P_1$.

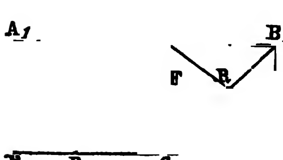


Fig. 52.

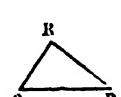


Fig. 53.

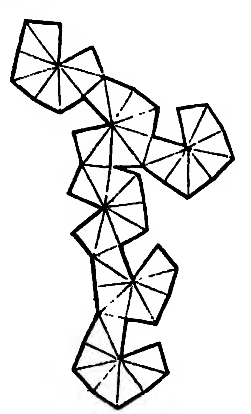


Fig. 54.

Let E D cut $A_1 C$ in O_1, and G F produced cut $C B_1$ in R_1. Join $P_1 O_1$, $P_1 R_1$, and $R_1 P_2$.

In C R_5 take C R_3 equal C R_1 and join R_3 O_1.

Then draw a line O_1 P_1 (Fig. 53), equal O_1 P_1 (Fig. 52) on O_1 P_1 (Fig. 53), as a base, describe a triangle, O_1 R P_1, having its side O_1 R equal to O_1 R_5 (Fig. 52), and the side P_1 R equal to P_1 R_1 of Fig. 52, then O_1 R P_1 will be a face of the required figure.

Forty-eight such faces arranged together, as in Fig. 54, will form the required net from which a model of the six-faced octahedron can be formed, which can be inscribed in the given cube.

Forms of the Six-faced Octahedron which occur in Nature.

The form 1, $\frac{5}{4}$, $\frac{5}{3}$ whose symbols are $\frac{5}{3}$ O $\frac{5}{4}$, Naumann; 5, 4, 3, Miller; and $b^{\frac{1}{5}}$, $b^{\frac{1}{4}}$, $b^{\frac{1}{3}}$, Brooke and Levy, has its octahedral axes $\frac{5}{12}$th and rhombic $\frac{5}{8}$th those of the cube in which it is inscribed.

Cos. $\theta = \frac{48}{50}$ $\theta = 168° 31'$, cos. $\phi = \frac{48}{50}$ $\phi = 168° 31'$ cos. $\psi = \frac{32}{50}$ $\psi = 129° 48'$.

Inclination of normals of faces whose inclinations to each other are θ ϕ and ψ respectively, 11°.29′, 11° 29′, and 50° 12′.

Faces parallel to this form occur in crystals of Pyrite.

The form 1, $\frac{64}{63}$, 64; 64 O $\frac{64}{63}$, Naumann; 64, 63, 1, Miller; b^1, $b^{\frac{1}{63}}$, $b^{\frac{1}{64}}$, Brooke and Levy. Octahedral axes $= \frac{1}{2}$; rhombic $= \frac{64}{127}$.

Cos. $\theta = \frac{4222}{8066}$ $\theta = 121° 31'$; cos. $\phi = \frac{8065}{8066}$ $\phi = 179° 6'$; cos. $\psi = \frac{8064}{8066}$ $\psi = 178° 43'$. Inclination of normals 58° 26′, 0° 54′, and 1° 17′.

Faces parallel to this form occur in crystals of Garnet.

The form 1, $\frac{4}{3}$, 2; 2O$\frac{4}{3}$, Naumann; 4, 3, 2, Miller; and $b^{\frac{1}{4}}$, $b^{\frac{1}{3}}$, $b^{\frac{1}{2}}$, Brooke and Levy, Octahedral axes $\frac{4}{6}$ and rhombic $\frac{4}{7}$.

Cos. $\theta = \frac{28}{29}$, $\theta = 164° 55'$; cos. $\phi = \frac{28}{29}$, $\phi = 164° 55'$; cos. $\psi = \frac{21}{29}$, $\psi = 136° 24'$ Inclination of normals, 15° 5′, 15° 5′, and 43° 36′.

Faces parallel to this form occur in crystals of Linneite.

The form 1, $\frac{15}{11}$, $\frac{15}{7}$; $\frac{15}{7}$ O $\frac{15}{11}$, Naumann; 15, 11, 7, Miller; and $b^{\frac{1}{15}}$, $b^{\frac{1}{11}}$, $b^{\frac{1}{7}}$. Brooke and Levy; octahedral axes, $\frac{15}{33}$; rhombic, $\frac{15}{26}$.

Cos. $\theta = \frac{378}{395}$, $\theta = 163° 38'$; cos. $\phi = \frac{378}{395}$, $\phi = 163° 38'$; cos. $\psi = \frac{337}{395}$, $\psi = 138.$ 45′. Inclination of normals, 16° 22′, 16° 22′, and 41° 15′.

Faces parallel to this form occur in Linneite.

The form 1, $\frac{4}{3}$, 4; 4 O $\frac{4}{3}$, Naumann; 4, 3, 1, Miller; and b^1, $b^{\frac{1}{3}}$, $b^{\frac{1}{4}}$, Brooke and Levy. Octahedral axes, $\frac{1}{2}$; rhombic. $\frac{4}{5}$.

Cos. $\theta = \frac{22}{26}$, $\theta = 147° 48'$; cos. $\phi = \frac{25}{26}$. $\phi = 164° 3'$; cos. $\psi = \frac{24}{26}$, $\psi = 157° 23'$. Inclination of normals, 32° 12′, 15° 57′, and 22° 37′.

Faces parallel to this form occur in Garnet.

The form 1, $\frac{3}{2}$, 3; 3 O $\frac{3}{2}$, Naumann; 3, 2, 1, Miller; and b^1, $b^{\frac{1}{2}}$, $b^{\frac{1}{3}}$, Brooke and Levy. Octahedral axes $= \frac{1}{2}$; rhombic, $\frac{3}{5}$.

Cos. $\theta = \frac{13}{14}$, $\theta = 158° 13'$; cos. $\phi = \frac{13}{14}$, $\phi = 158° 13'$; cos. $\psi = \frac{12}{14}$, $\psi = 149° 0'$. Inclination of normals, 21° 47′, 21° 47,′ and 31° 0′.

Faces parallel to this form occur in

Amalgam.	Diamond.	Hauerite.
Cobaltine.	Fahlerz.	Magnetite.
Cuprite.	Garnet.	Pyrite.

The form 1, $\frac{5}{3}$, 5; 5 O $\frac{5}{3}$, Naumann; 5, 3, 1, Miller; b^1, $b^{\frac{1}{3}}$, $b^{\frac{1}{5}}$, Brooke and Levy; octahedral axes, $\frac{5}{9}$; rhombic, $\frac{5}{8}$.

Cos. $\theta = \frac{31}{35}$, $\theta = 152° 20'$; cos. $\phi = \frac{31}{35}$, $\phi = 152° 20'$; cos. $\psi = \frac{33}{35}$, $\psi = 160° 32'$. Inclination of normals, 27° 40′, 27° 40′, and 19° 28′.

Faces parallel to this form occur in Boracite and Pyrite.

The form 1, 2, 4; 4 O 2, Naumann; 4, 2, 1, Miller; b^1, $b^{\frac{1}{2}}$, $b^{\frac{1}{4}}$, Brooke and Levy. Octahedral axes, $\frac{4}{7}$; rhombic, $\frac{2}{3}$.

Cos. $\theta = \frac{20}{21}$, $\theta = 162° \ 15'$; cos. $\phi = \frac{17}{21}$, $\phi = 144° \ 3'$; cos. $\psi = \frac{19}{21}$, $\psi = 154° \ 47'$. Inclination of normals, 17° 45′, 35° 57′, and 25° 13′.

Faces parallel to this form occur in Fluor, Gold, and Pyrite.

The form 1, $\frac{11}{5}$, $\frac{11}{3}$; $\frac{11}{3}$ O $\frac{11}{5}$, Naumann; 11, 5, 3, Miller; $6^{\frac{1}{11}}$, $6^{\frac{1}{5}}$, $6^{\frac{1}{3}}$, Brooke and Levy. Octahedral axes, $\frac{11}{15}$; rhombic axes, $\frac{11}{16}$

Cos. $\theta = \frac{151}{155}$, $\theta = 166° \ 57'$; cos. $\phi = \frac{119}{155}$, $\phi = 140° \ 9'$; cos. $\psi = \frac{137}{155}$, $\psi = 152° \ 7'$. Inclination of normals, 13° 3′, 39° 51′, and 27° 53′.

Faces parallel to this form occur in crystals of Fluor.

The form 1, $\frac{16}{7}$, 4; 4 O $\frac{16}{7}$, Naumann; 16, 7, 4, Miller; $6^{\frac{1}{4}}$, $6^{\frac{1}{7}}$, $6^{\frac{1}{16}}$, Brooke and Levy. Octahedral axes, $\frac{16}{27}$; rhombic axes, $\frac{16}{23}$.

Cos. $\theta = \frac{312}{321}$, $\theta = 166° \ 24'$; cos. $\phi = \frac{240}{321}$, $\phi = 138° \ 23'$; cos $\psi = \frac{289}{321}$, $\psi = 154° \ 12'$. Inclination of normals, 13° 36′, 41° 37′, and 25° 48′.

Faces parallel to this form occur in crystals of Fluor.

The form 1, $\frac{7}{3}$, 7; 7 O $\frac{7}{3}$, Naumann; 7, 3, 1, Miller; b^1, $6^{\frac{1}{3}}$, $6^{\frac{1}{7}}$, Brooke and Levy. Octahedral axes, $\frac{7}{11}$; rhombic, $\frac{7}{10}$.

Cos. $\theta = \frac{55}{59}$, $\theta = 158° \ 47'$; cos. $\phi = \frac{43}{59}$, $\phi = 136° \ 47'$; cos. $\psi = \frac{57}{59}$, $\psi = 165° \ 2'$. Inclination of normals, 21° 15′, 43° 13′, and 14° 58′.

Faces parallel to this form occur in crystals of Fluor.

The form 1, 4, 8; 8 O 4, Naumann; 8, 2, 1, Miller; b^1, $b^{\frac{1}{2}}$, b^1, Brooke and Levy. Octahedral axes, $\frac{8}{11}$; rhombic axes, $\frac{4}{5}$.

Cos. $\theta = \frac{68}{69}$, $\theta = 170° \ 14'$; cos. $\phi = \frac{33}{69}$, $\phi = 118° \ 34'$; cos. $\psi = \frac{67}{69}$, $\psi = 166° \ 10'$. Inclination of normals, 9° 46′, 61° 26′, and 13° 50′.

Faces parallel to this form have been found in crystals of Galena.

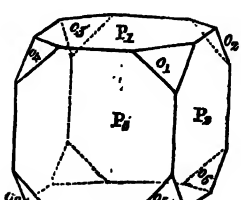


Fig. 55.

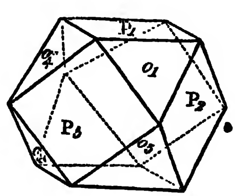


Fig. 56.

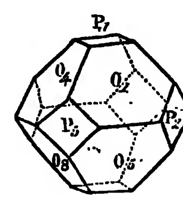


Fig. 57.

Combination of the Forms of the Cube and Octahedron.—When the faces of the cube P_1 P_2, &c., P_6 (Fig. 55), predominate, the solid angles of the cube are replaced by triangular faces o_1 o_2, &c., o_8, which are parallel to those of the inscribed octahedron. When the faces o_1 o_2, &c., o_8, are so large that the angles of their triangles meet, P_1 P_2, &c., P_6, are squares (Fig. 56). When the faces of the octahedron predominate, as in Fig. 57, the solid angles of the octahedron are replaced by square planes of the cube P_1 P_2, &c., P_6.

If θ be the angle of inclination of a face of the octahedron, as o_1, to any of the adjacent faces of the cube, as P_1 P_2, or P_5,

$$\text{Cos. } \theta = \frac{1}{\sqrt{3}} \quad \theta = 125° \ 16'.$$

Inclination of normals, o_1 and $P_1 = 54° \ 44'$.

Combination of Cube and Rhombic Dodecahedron.—When the faces of the cube P_1 P_2 P_3, &c., (Fig. 58), predominate, the faces of the rhombic dodecahedron, r_1 r_4 r_5, replace the edges of the cube.

When the faces of rhombic dodecahedron predominate (Fig. 59), the faces of the cube P_1 P_2 P_5, replace the four-faced solid angles of the rhombic dodecahedron with square planes, P_1 P_2, &c.

If θ be the angle of inclination of the face of the cube P_1 to the adjacent faces of the rhombic dodecahedron r_1 r_4, &c., and θ' the inclination of their normals,

$$\text{Cos. } \theta = \frac{1}{\sqrt{2}} \quad \theta = 135^\circ\text{, and } \theta' = 45^\circ.$$

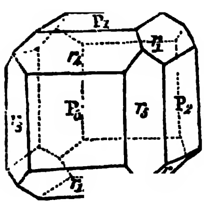


Fig. 58.

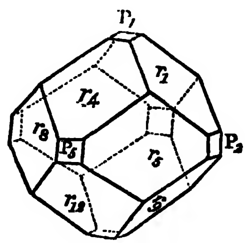


Fig. 59.

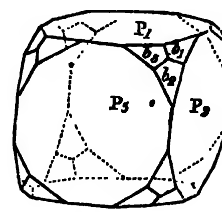


Fig. 60.

Combination of Cube and Three-faced Octahedron.—When the faces of the cube, P_1 P_2 P_3, &c. (Fig. 60), predominate, the solid angles of the cube are replaced by the three-faced solid angles of the three-faced octahedron, forming three trapezoidal planes, b_1 b_2, and b_3, for each solid angle of the cube.

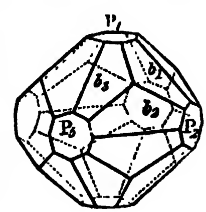


Fig. 61.

When the faces of the three-faced octahedron, b_1 b_2 b_3, &c., predominate (Fig. 61), the eight-faced solid angles of the three-faced octahedron are replaced by octagonal planes of the cube P_1 P_2 P_5, &c.

Let θ be the angle of inclination of P_1 to b_1 or b_3, θ' that of their normals, and ϕ the angle of inclination of P_1 to b_2, ϕ' that of their normals.

If $11n$ be the symbol of the three-faced octahedron,

$$\cos.\ \theta = \frac{1}{\sqrt{2 + \frac{1}{n^2}}} \quad \theta' = 180^\circ - \theta \quad \cos.\ \phi = \frac{\cos.\ \theta}{n} \quad \varphi' = 180^\circ - \phi.$$

For the form 1, 1, $\frac{65}{64}$ cos. $\theta = \sqrt{\frac{4225}{12546}}$ $\theta' = 125^\circ\ 28'$ $\theta' = 54^\circ\ 32'$.
cos. $\phi = \sqrt{\frac{4096}{12546}}$ $\phi = 124^\circ\ 51'$ $\phi' = 55^\circ\ 9'$.

For the form 1, 1, $\frac{5}{4}$, cos. $\theta = \sqrt{\frac{25}{66}}$ $\theta = 127^\circ\ 59'$ $\theta' = 52^\circ\ 1'$.
cos. $\phi = \sqrt{\frac{16}{66}}$ $\phi = 119^\circ\ 29'$ $\phi' = 60^\circ\ 31'$.

For the form 1, 1, $\frac{3}{2}$, cos. $\theta = \sqrt{\frac{9}{22}}$ $\theta = 129^\circ\ 46'$ $\theta' = 50^\circ\ 14'$.
cos. $\phi = \sqrt{\frac{4}{22}}$ $\phi = 115^\circ\ 15'$ $\phi' = 64^\circ\ 45'$.

For the form 1, 1, $\frac{7}{4}$, cos. $\theta = \sqrt{\frac{49}{114}}$ $\theta = 130^\circ\ 58'$ $\theta' = 49^\circ\ 2'$.
cos. $\phi = \sqrt{\frac{16}{114}}$ $\phi = 112^\circ\ 0'$ $\phi' = 68^\circ\ 0'$.

For the form 1, 1, 2, cos. $\theta = \sqrt{\frac{4}{9}}$ $\theta = 131^\circ\ 49'$ $\theta' = 48^\circ\ 11'$.
cos. $\phi = \sqrt{\frac{1}{9}}$ $\phi = 109^\circ\ 29'$ $\phi' = 70^\circ\ 31'$.

For the form 1, 1, 3, cos. $\theta = \sqrt{\frac{9}{19}}$ $\theta = 133° \, 30'$ $\theta' = 46° \, 30'$.

cos. $\phi = \sqrt{\frac{1}{19}}$ $\phi = 103° \, 16'$ $\phi' = 76° \, 44'$.

For the form 1, 1, 4, cos. $\theta = \sqrt{\frac{16}{33}}$ $\theta = 134° \, 8'$ $\theta' = 45° \, 52'$.

cos. $\phi = \sqrt{\frac{1}{33}}$ $\phi = 100° \, 1'$ $\phi' = 79° \, 59'$.

Combination of Cube and Twenty-four-faced Trapezohedron.—When the faces of the cube P_1 P_2 P_5, &c., predominate (Fig. 62), the solid angles of the cube are replaced by the three-faced solid angles of the Trapezohedron forming three triangular planes a_1 a_2 a_3 for each solid angle of the cube.

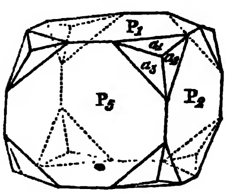


Fig. 62.

When the faces of the trapezohedron predominate (Fig. 63), the four-faced solid angles of the trapezohedron, which terminate the cubical axes, are replaced by square planes of the cube P_1 P_2 P_5, &c. Let θ be the angle of inclination of P_1 to a_1, θ' that of their normals, and ϕ the angle of inclination of P_1 to a_2 or a_3, ϕ' that of their normals.

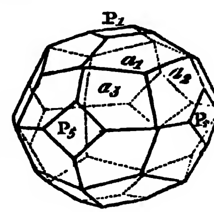


Fig. 63.

If 1 m m be the symbol of the twenty-four-faced trapezohedron,

$$\sqrt{1 + \frac{2}{m^2}}, \qquad ' = 180° - \phi.$$

For the form 1, $\frac{4}{3}$, $\frac{4}{3}$, cos. $\theta = \sqrt{\frac{16}{34}}$ $\theta = 133° \, 19'$ $\theta' = 46° \, 41'$.

cos. $\phi = \sqrt{\frac{9}{34}}$ $\phi = 120° \, 58'$ $\phi' = 59° \, 2'$.

For the form 1, $\frac{3}{2}$, $\frac{3}{2}$, cos. $\theta = \sqrt{\frac{9}{17}}$ $\theta = 136° \, 41'$ $\theta' = 43° \, 19'$.

cos. $\phi = \sqrt{\frac{4}{17}}$ $\phi = 119° \, 1'$ $\phi' = 60° \, 59'$.

For the form 1, 2, 2, cos. $\theta = \sqrt{\frac{2}{3}}$ $\theta = 144° \, 44'$ $\theta' = 35° \, 16'$.

cos. $\phi = \sqrt{\frac{1}{6}}$ $\phi = 114° \, 6'$ $\phi' = 65° \, 54'$.

For the form 1, $\frac{9}{4}$, $\frac{9}{4}$, cos. $\theta = \sqrt{\frac{81}{113}}$ $\theta = 147° \, 51'$ $\theta' = 32° \, 9'$.

cos. $\phi = \sqrt{\frac{16}{113}}$ $\phi = 112° \, 6'$ $\phi' = 67° \, 54'$.

For the form 1, $\frac{8}{3}$, $\frac{8}{3}$, cos. $\theta = \sqrt{\frac{64}{82}}$ $\theta = 152° \, 4'$ $\theta' = 27° \, 56'$.

cos. $\phi = \sqrt{\frac{9}{82}}$ $\phi = 109° \, 21'$ $\phi' = 70° \, 39'$.

For the form 1, 3, 3, cos. $\theta = \sqrt{\frac{9}{11}}$ $\theta = 154° \, 46'$ $\theta' = 25° \, 14'$.

cos. $\phi = \sqrt{\frac{1}{11}}$ $\phi = 107° \, 33'$ $\phi' = 72° \, 27'$.

For the form 1, 4, 4, cos. $\theta = \sqrt{\frac{16}{18}}$ $\theta = 160° \, 32'$ $\theta' = 19° \, 28'$.

cos. $\phi = \sqrt{\frac{1}{18}}$ $\phi = 103° \, 38'$ $\phi' = 76° \, 22'$.

For the form 1, 10, 10, cos. $\theta = \sqrt{\frac{100}{102}}$ $\theta = 171° \, 57'$ $\theta' = 8° \, 3'$.

cos. $\phi = \sqrt{\frac{1}{102}}$ $\phi = 95° \, 41'$ $\phi' = 84° \, 19'$.

For the form 1, 12, 12, cos. $\theta = \sqrt{\frac{144}{146}}$ $\theta = 173° 17'$ $\theta' = 6° 43'$.

cos. $\phi = \sqrt{\frac{1}{146}}$ $\phi = 99° 45'$ $\phi' = 85° 15'$.

For the form 1, 16, 16, cos. $\theta = \sqrt{\frac{256}{258}}$ $\theta = 174° 57'$ $\theta' = 5° 3'$.

cos. $\phi = \sqrt{\frac{1}{258}}$ $\phi = 93° 34'$ $\phi' = 86° 26'$.

For the form 1, 40, 40, cos. $\theta = \sqrt{\frac{800}{801}}$ $\theta = 177° 8'$ $\theta' = 2° 52'$.

cos. $\phi = \sqrt{\frac{1}{1602}}$ $\phi = 91° 26'$ $\phi' = 88° 34'$.

Combination of Cube and Four-faced Cube.—When the faces of the cube P_1 P_2 P_5, &c. (Fig. 64) predominate, each edge of the cube is replaced or bevelled by two faces of the four-faced cube c_1 c_2, c_3 c_4, c_5 c_6, &c.

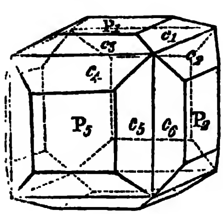


Fig. 64.

When the faces of the four-faced cube c_1 c_2 c_3, &c. (Fig. 65) predominate, every four-faced solid angle of the four-faced cube is replaced by a square plane, P_1 P_2, &c., of the cube.

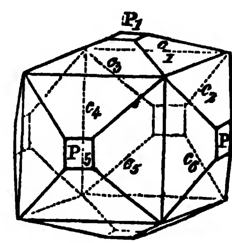


Fig. 65.

If 1, m, ∞ be the symbol of the four-faced cube,

θ the angle of inclination of P_1 to c_1 or c_3, θ' that of their normals.

ϕ the angle of inclination of P_1 to c_2 or c_4, ϕ' that of their normals.

$$\text{Then cos. } \theta = \frac{1}{\sqrt{1 + \frac{1}{m^2}}} \text{ or cot. } \theta = m,\ \theta' = 180 - \theta,\ \text{cos. } \phi = \frac{\text{cos. } \theta}{m},$$

and $\phi' = 180° - \phi$.

The inclination of P_1 to c_5 or c_6 is 90° in every case.

For the form 1, $\frac{5}{4}$, ∞, cos. $\theta = \sqrt{\frac{25}{41}}$ cot. $\theta = \frac{5}{4}$ $\theta = 141° 20'$ $\theta' = 36° 40'$.

cos. $\phi = \sqrt{\frac{16}{41}}$ $\phi = 128° 40'$ $\phi' = 51° 20'$.

For the form 1, $\frac{4}{3}$, ∞, cos. $\theta = \sqrt{\frac{16}{25}}$ cot. $\theta = \frac{4}{3}$ $\theta = 143° 8'$ $\theta' = 36° 52'$.

cos. $\phi = \sqrt{\frac{9}{25}}$ $\phi = 126° 52'$ $\phi' = 53° 8'$.

For the form 1, $\frac{3}{2}$, ∞, cos. $\theta = \sqrt{\frac{9}{13}}$ cot. $\theta = \frac{3}{2}$, $\theta = 146° 19'$ $\theta' = 33° 41'$.

cos. $\phi = \sqrt{\frac{4}{13}}$ $\phi = 123° 41'$ $\phi' = 56° 19'$.

For the form 1, 2, ∞, cos. $\theta = \sqrt{\frac{4}{5}}$ cot. $\theta = 2$ $\theta = 153° 26'$ $\theta' = 26° 34'$.

cos. $\phi = \sqrt{\frac{1}{5}}$ $\phi = 116° 34'$ $\phi' = 63° 26'$.

For the form 1, $\frac{5}{2}$, ∞, cos. $\theta = \sqrt{\frac{25}{29}}$ cot. $\theta = \frac{5}{2}$ $\theta = 158° 12'$ $\theta' = 21° 48'$.

cos. $\phi = \sqrt{\frac{4}{29}}$ $\phi = 111° 48'$ $\phi' = 68° 12'$.

For the form 1, 3, ∞, cos. $\theta = \sqrt{\frac{9}{10}}$ cot. $\theta = 3$ $\theta = 161° 34'$ $\theta' = 18° 26'$.

cos. $\phi = \sqrt{\frac{1}{10}}$ $\phi = 108° 26'$ $\phi' = 71° 34'$.

For the form 1, 4, ∞, cos. $\theta = \sqrt{\frac{16}{17}}$ cot. $\theta = 4$ $\theta = 165° 58'$ $\theta' = 14° 2'$.

cos. $\phi = \sqrt{\frac{1}{17}}$ $\phi = 104° 2'$ $\phi' = 75° 58'$.

For the form 1, 5, ∞, cos. $\theta = \sqrt{\frac{25}{26}}$ cot. $\theta = 5$ $\theta = 168° 41'$ $\theta' = 11° 19'$.

cos. $\phi = \sqrt{\frac{1}{26}}$ $\phi = 101° 19'$ $\phi' = 78° 41'$.

Combination of Cube and Six-faced Octahedron.—When the faces of the cube P_1 P_2 P_5, &c. (Fig. 66), predominate, each solid angle of the cube is replaced by a six-faced solid angle of the six-faced octahedron, forming six triangular planes e_1 e_2 e_3 e_4 e_5 e_6 for each solid angle of the cube.

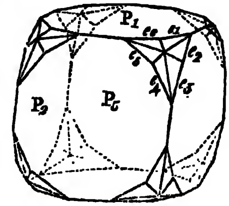


Fig. 66.

When the faces of six-faced octahedron e_1 e_2 e_3, &c. (Fig. 67), predominate, the eight-faced solid angles of the six-faced octahedron are replaced by octagonal planes P_1 P_2, &c., of the cube.

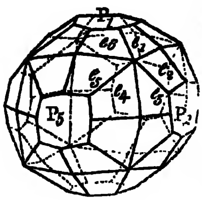


Fig. 67.

If 1, m, n be the symbol of the six-faced octahedron,

θ the angle of inclination of P_1 to e_1, or e_6, θ' that of their normals.

ϕ the angle of inclination of P_1 to e_2, or e_5, ϕ' that of their normals.

ψ the angle of inclination of P_1 to e_3, or e_4, ψ' that of their normals.

$$\text{Cos. } \theta = \frac{1}{\sqrt{1 + \frac{1}{m^2} + \frac{1}{n^2}}} \quad \theta' = 180^\circ - \theta \quad \cos. \phi = \frac{\cos. \theta}{m} \quad \phi' = 180^\circ - \phi \text{ ; } \cos. \psi = \frac{\cos. \theta}{n} \quad \psi' = 180^\circ - \psi.$$

For the form 1, $\frac{5}{4}$, $\frac{5}{3}$, $\theta = 135^\circ\ 0'$, $\theta = 45^\circ\ 0'$; $\phi = 124^\circ\ 27'$, $\phi' = 55^\circ\ 33'$; $\psi = 115^\circ\ 16'$, $\psi' = 64^\circ\ 54'$.

For the form 1, $\frac{64}{63}$, 64, $\theta = 135^\circ\ 37'$, $\theta' = 44^\circ\ 3?'$; $\phi = 134^\circ\ 33'$, $\phi' = 45^\circ\ 27'$; $\psi = 90^\circ\ 38'$, $\psi' = 89^\circ\ 22'$.

For the form 1, $\frac{4}{3}$, 2, $\theta = 137^\circ\ 58'$, $\theta' = 42^\circ\ 2'$; $\phi = 123^\circ\ 51'$, $\phi' = 56^\circ\ 9'$; $\psi = 111^\circ\ 48'$, ψ' $68^\circ\ 12'$.

For the form 1, $\frac{14}{11}$ $\frac{15}{7}$, $\theta = 139^\circ\ 0,'$ $\theta' = 41^\circ\ 0'$; $\phi = 123^\circ\ 36'$, $\phi' = 56^\circ\ 24'$ $\psi = 110^\circ\ 37'$, $\psi' = 69^\circ\ 23'$.

For the form 1, $\frac{4}{3}$, 4, $\theta = 141^\circ\ 40'$, $\theta' = 38^\circ\ 20'$; $\phi = 126^\circ\ 2'$, $\phi' = 53^\circ\ 58'$ $\psi = 101^\circ\ 19'$, $\psi' = 78^\circ\ 41'$.

For the form 1, $\frac{3}{2}$, 3, $\theta = 143^\circ\ 18'$, $\theta' = 36^\circ\ 42'$; $\phi = 122^\circ\ 19'$, $\phi' = 57^\circ\ 41'$; $\psi = 105^\circ\ 30'$, $\psi' = 74^\circ\ 30'$.

For the form 1, $\frac{5}{3}$, 5, $\theta = 147^\circ\ 41'$, $\theta' = 32^\circ\ 19'$; $\phi = 120^\circ\ 28'$, $\phi' = 59^\circ\ 32'$; $\psi = 99^\circ\ 4'$, $\psi' = 80^\circ\ 16'$.

For the form 1, 2, 4, $\theta = 150^\circ\ 48'$, $\theta' = 29^\circ\ 12'$; $\phi = 115^\circ\ 53'$, $\phi = 64^\circ\ 7'$; $\psi = 102^\circ\ 36'$, $\psi' = 77^\circ\ 24'$.

For the form 1, $\frac{11}{5}$, $\frac{11}{3}$, $\theta = 152^\circ\ 4'$, $\theta' = 27^\circ\ 56'$; $\phi = 113^\circ\ 41'$, $\phi' = 66^\circ\ 19'$; $\psi = 103^\circ\ 57'$, $\psi' = 76^\circ\ 3'$.

For the form 1, $\frac{16}{7}$, 4, $\theta = 153^\circ\ 15'$, $\theta' = 26^\circ\ 45'$; $\phi = 113^\circ\ 0'$, $\phi' = 67^\circ\ 0'$; $\psi = 102^\circ\ 54'$, $\psi' = 77^\circ\ 6'$.

For the form 1, $\frac{7}{6}$, 7, $\theta = 155^\circ\ 41'$, $\theta' = 24^\circ\ 19'$; $\phi = 112^\circ\ 59'$, $\phi' = 67^\circ\ 1'$ $\psi = 97^\circ\ 29'$, $\psi' = 82^\circ\ 31'$.

For the form 1, 4, 8, $\theta = 164^\circ\ 23'$, $\theta' = 15^\circ\ 37'$; $\phi = 103^\circ\ 56'$, $\phi' = 76^\circ\ 4'$ $\psi = 96^\circ\ 55'$, $\psi' = 83^\circ\ 5'$.

Combination of Octahedron and Rhombic Dodecahedron.—When the faces of the octahedron predominate, as o_1 o_4 o_8, &c. (Fig. 68), the planes of the rhombic dodecahedron r_1 r_5 r_4, &c., replace or truncate the edges of the octahedron.

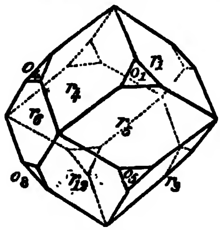


Fig. 69

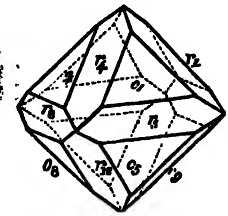


Fig. 68.

When the faces of the rhombic dodecahedron predominate, as $r_1 r_4 r_5$, &c. (Fig. 69), the three-faced solid angles of the rhombic dodecahedron are replaced by triangular planes o_1 o_4 o_8, &c. of the octahedron.

The inclination of o_1 to any of the adjacent faces r_1, r or r_5, is 144° 44′, that of their normals 35° 16′.

Combination of the Octahedron and Three-faced Octahedron.—When the faces of the octahedron o_1 o_4 o_5 o, &c. (Fig. 70), predominate, the edges of the octahedron are replaced or bevelled by two planes of the three-faced octahedron.

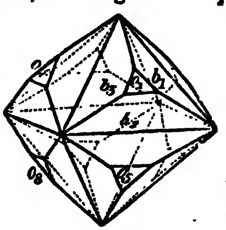


Fig. 71.

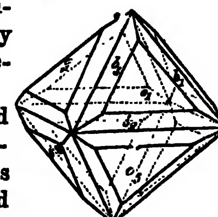


Fig. 70.

When the faces of the three-faced octahedron b_1 b_2 b_3, &c. (Fig. 71), predominate, the three-faced solid angles of the three-faced octahedron are replaced by triangular planes o_1, o_4, o_5, o_8, &c., of the octahedron.

If $11n$ be the symbol of the three-faced octahedron, θ the angle of inclination of o_1 to b_1, b_2, or b_3, θ' that of their normals,

$$\text{Then } \cos.\ \theta = \frac{2 + \frac{1}{n}}{\sqrt{3\left(2 + \frac{1}{n^2}\right)}} \text{ and } \theta' = 180^\circ - \theta.$$

For the form 1, 1, $\frac{34}{33}$ $\theta = 179^\circ\ 35'$ $\theta' = 0^\circ\ 25'$.

For the form 1, 1, $\frac{5}{4}$ $\theta = 174^\circ\ 14'$ $\theta' = 5^\circ\ 46'$.

For the form 1, 1, $\frac{3}{2}$ $\theta = 169^\circ\ 57'$ $\theta' = 10^\circ\ 3'$.

For the form 1, 1, $\frac{7}{4}$ $\theta = 166^\circ\ 44'$ $\theta' = 13^\circ\ 16'$.

For the form 1, 1, 2 $\theta = 164^\circ\ 12'$ $\theta' = 15^\circ\ 58'$.

For the form 1, 1, 3 $\theta = 158^\circ\ 0'$ $\theta' = 22^\circ\ 0'$.

For the form 1, 1, 4 $\theta = 154^\circ\ 46'$ $\theta' = 25^\circ\ 14'$.

Combination of the Octahedron and Twenty-four Faced Trapezohedron.—When the faces of the octahedron o_1 o_4 o_5 o_8 (Fig. 72) predominate, the solid angles of the octahedron are replaced by the four-faced solid angles of the trapezohedron, which terminate its cubical axes.

When the faces a_1 a_2 a_3, &c. (Fig. 73), of the trapezohedron predominate, the three-faced solid angles of the trapezohedron are replaced by triangular planes o_1, o_4, o_5, o_8, of the octahedron.

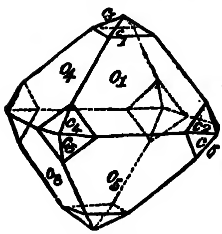


Fig. 72.

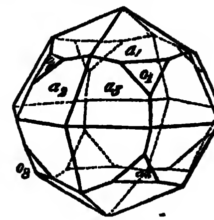


Fig. 73.

If 1, m, m be the symbol of the twenty-four-faced trapezohedron, θ the angle of inclination of the face o_1 to a_1, a_2, or a_3; θ' that of their normals.

$$\text{Cos. } \theta = \frac{1 + \frac{2}{m}}{3\,(1 + \frac{2}{m^2})} \qquad \theta' = 180^\circ -$$

For the form 1, $\frac{4}{3}$ $\frac{4}{3}$	$\theta = 171^\circ\ 57'$	$\theta' = 8^\circ\ 3'$.
For the form 1, $\frac{3}{2}$, $\frac{3}{2}$	$\theta = 168^\circ\ 35'$	$\theta' = 11^\circ\ 25'$.
For the form 1, 2, 2	$\theta = 160^\circ\ 32'$	$\theta' = 19^\circ\ 28'$.
For the form 1, $\frac{9}{4}$, $\frac{9}{4}$	$\theta = 157^\circ\ 25'$	$\theta' = 22^\circ\ 35'$.
For the form 1, $\frac{8}{3}$, $\frac{8}{3}$	$\theta = 153^\circ\ 12'$	$\theta' = 26^\circ\ 48'$.
For the form 1, 3, 3	$\theta = 150^\circ\ 30'$	$\theta' = 29^\circ\ 30'$.
For the form 1, 4, 4	$\theta = 144^\circ\ 44'$	$\theta' = 35^\circ\ 16'$.
For the form 1, 10, 10	$\theta = 133^\circ\ 19'$	$\theta' = 46^\circ\ 41'$.
For the form 1, 12, 12	$\theta = 131^\circ\ 59'$	$\theta' = 48^\circ\ 1'$.
For the form 1, 16, 16	$\theta = 130^\circ\ 19'$	$\theta' = 49^\circ\ 41'$.
For the form 1, 40, 40	$\theta = 127^\circ\ 17'$	$\theta' = 52^\circ\ 43'$.

Combination of the Octahedron and Four-faced Cube.—When the faces of the octahedron, $o_1\,o_4\,o_5\,o_8$ (Fig. 74), predominate, the solid angles of the octahedron are replaced by the four-faced solid angles of the four-faced cube c_1 c_3, &c.

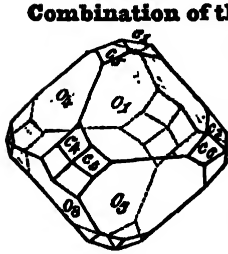


Fig. 74.

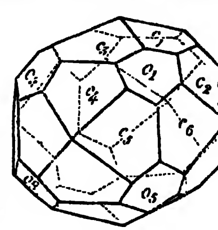


Fig. 75.

When the faces of the four-faced cube c_1 c_2 c_3, &c. (Fig. 75), predominate, the six-faced solid angles of the four-faced cube are replaced by planes of the octahedron o_1, o_4, o_5, o_8, &c.

If θ be the angle of inclination of the face o_1 of the octahedron, to any of the faces c_1 c_2 c_3 c_4 c_5 c_6 of the four-faced cube whose symbol is 1 m ∞, θ' that of their normals.

$$\text{Cos. } \theta = \frac{1 + \frac{1}{m}}{\sqrt{3\,(1 + \frac{1}{m^2})}} \qquad ' = 180^\circ -$$

For the form 1, $\frac{5}{4}$, ∞	$\theta = 144^\circ\ 15'$	$\theta' = 35^\circ\ 45'$.
For the form 1, $\frac{4}{3}$, ∞	$\theta = 143^\circ\ 56'$	$\theta' = 36^\circ\ 49'$.
For the form 1, $\frac{3}{2}$, ∞	$\theta = 143^\circ\ 11'$	$\theta' = 36^\circ\ 49'$.
For the form 1, 2, ∞	$\theta = 141^\circ\ 46'$	$\theta' = 39^\circ\ 14'$.
For the form 1, $\frac{5}{2}$, ∞	$\theta = 139^\circ\ 38'$	$\theta' = 41^\circ\ 22'$.

For the form 1, 3, ∞ $\theta = 136° 55'$ $\theta' = 43° 5'$.
For the form 1, 4, ∞ $\theta = 134° 26'$ $\theta' = 45° 34'$.
For the form 1, 5, ∞ $\theta = 132° 48'$ $\theta' = 47° 12'$.

Combination of the Octahedron and Six-faced Octahedron.—When the faces o_1 o_4 o_5 o_8 (Fig, 76), of the octahedron predominate, the solid angles of the octahedron are replaced by the eight-faced solid angles of the six-faced octahedron.

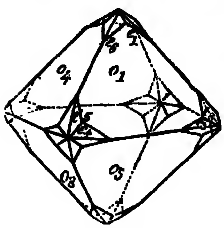


Fig. 76.

When the faces e_1 e_2 e_3 e_4, &c. (Fig. 77), of the six-faced octahedron predominate, each six-faced solid angle of the six-faced octahedron is replaced by a plane, o_1 o_4 o_5, &c. of the octahedron.

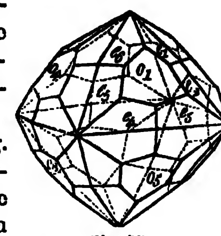


Fig. 77.

If 1, m, n be the symbol of the six-faced octahedron, θ the angle of inclination of a face of the octahedron o_1 to any of the six adjacent faces e_1 e_2 e_3 e_4 e_5 or e_6 of the six-faced octahedron, θ' that of their normals,

$$\text{Cos. } \theta = \frac{1 + \frac{1}{m} + \frac{1}{n}}{\sqrt{3\left(1 + \frac{1}{m^2} + \frac{1}{n^2}\right)}} \qquad \theta' = 180° - \theta.$$

For the form 1, $\frac{5}{4}$, $\frac{5}{3}$ $\theta = 168° 28'$ $\theta' = 11° 32'$.
For the form 1, $\frac{64}{63}$, 64 $\theta = 145° 22'$ $\theta' = 34° 38'$.
For the form 1, $\frac{4}{3}$, 2 $\theta = 164° 47'$ $\theta' = 15° 13'$.
For the form 1, $\frac{15}{11}$, $\frac{15}{7}$ $\theta = 163° 28'$ $\theta' = 16° 32'$.
For the form 1, $\frac{4}{3}$, 4 $\theta = 154° 56'$ $\theta' = 25° 4'$.
For the form 1, $\frac{3}{2}$, 3 $\theta = 157° 47'$ $\theta' = 22° 13'$.
For the form 1, $\frac{5}{3}$, 5 $\theta = 151° 26'$ $\theta' = 28° 34'$.
For the form 1, 2, 4 $\theta = 151° 52'$ $\theta' = 28° 8'$.
For the form 1, $\frac{11}{5}$, $\frac{11}{3}$ $\theta = 151° 47'$ $\theta' = 28° 13'$.
For the form 1, $\frac{16}{7}$, 4 $\theta = 150° 28'$ $\theta' = 29° 32'$.
For the form 1, $\frac{7}{3}$, 7 $\theta = 145° 46'$ $\theta' = 34° 14'$.
For the form 1, 4, 8 $\theta = 139° 52'$ $\theta' = 40° 8'$.

Combination of the Rhombic Dodecahedron and Three-faced Octahedron.—When the faces of the rhombic dodecahedron r_1 r_4 r_5 &c. (Fig. 78), predominate, a three-faced solid angle of the three-faced octahedron replaces each three-faced solid angle of the rhombic dodecahedron.

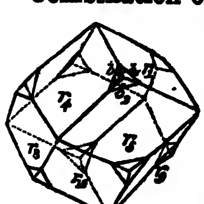


Fig. 78.

When the faces of three-faced octahedron b_1 b_2 b_3, &c. (Fig. 79), predominate, each edge of the three-faced octahedron, which joins its eight-faced solid angles, is replaced by a plane of the rhombic dodecahedron.

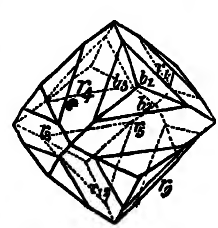


Fig. 79.

If 1, 1 n be the symbol of the three-faced octahedron, θ the angle of inclination of b_1 to r_1, or b_3 to r_4, θ' that of their normals,

$$\text{Cos. } \theta = \frac{}{\sqrt{2\left(2+\frac{1}{n^2}\right)}} \qquad \theta' = 180^\circ - \theta.$$

For the form 1, 1, $\frac{65}{64}$	$\theta = 145^\circ\ 9'$	$\theta' = 34^\circ\ 51'$.
For the form 1, 1, $\frac{5}{4}$	$\theta = 150^\circ\ 30'$	$\theta' = 29^\circ\ 30'$.
For the form 1, 1, $\frac{3}{2}$	$\theta = 154^\circ\ 46'$	$\theta' = 25^\circ\ 14'$.
For the form 1, 1, $\frac{7}{4}$	$\theta = 158^\circ\ 0'$	$\theta' = 22^\circ\ 0'$.
For the form 1, 1, 2	$\theta = 160^\circ\ 32'$	$\theta' = 19^\circ\ 28'$.
For the form 1, 1, 3	$\theta = 166^\circ\ 44'$	$\theta' = 13^\circ\ 16'$.
For the form 1, 1, 4	$\theta = 169^\circ\ 58'$	$\theta' = 10^\circ\ 2'$.

Combination of the Rhombic Dodecahedron and Twenty-four-Faced Trapezohedron.—For the trapezohedron, whose symbol is 1, 2, 2,

When the faces of the rhombic dodecahedron r_1 r_4 r_5, &c. (Fig. 80), predominate, the edges of the rhombic dodecahedron are replaced by planes a_1 a_2 a_3, &c. of the trapezohedron.

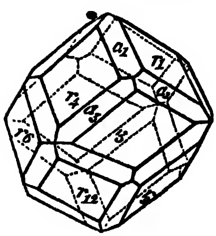


Fig. 80.

When the faces of the same form of the trapezohedron a_1 a_2 a_3, &c. (Fig. 81), predominate, each four-faced solid angle of the trapezohedron, which terminates its rhombic axis, is replaced by a plane of the rhombic dodecahedron r_1 r_4 r_5, &c.

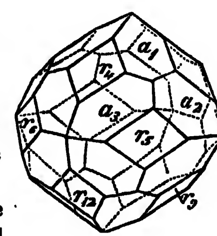


Fig. 81.

If 1 m m be the symbol of the trapezohedron, when m is greater than 2, the four-faced solid angles of the rhombic dodecahedron are replaced by the four-faced solid angles of the trapezohedron, which terminate its cubical axes. When m is less than 2, the three-faced solid angles of the rhombic dodecahedron are replaced by the three-faced solid angles of the trapezohedron.

If 1 m m be the symbol of the twenty-four-faced trapezohedron, θ the inclination of a_1 to r_1 or r_4, of a_2 to r_1 or r_5, &c., θ' that of their normals,

$$\text{Cos. } \theta = \frac{1+\frac{1}{m}}{\sqrt{2\left(1+\frac{2}{m^2}\right)}} \qquad \theta' = 180^\circ - \theta.$$

For the form 1, $\frac{4}{3}$, $\frac{4}{3}$	$\theta = 148^\circ\ 5'$	$\theta' = 31^\circ\ 55'$.
For the form 1, $\frac{3}{2}$, $\frac{3}{2}$	$\theta = 149^\circ\ 2'$	$\theta' = 30^\circ\ 58'$.
For the form 1, 2, 2	$\theta = 150^\circ\ 0'$	$\theta' = 30^\circ\ 0'$.
For the form 1, $\frac{9}{4}$, $\frac{9}{4}$	$\theta = 149^\circ\ 51'$	$\theta' = 30^\circ\ 9'$.
For the form 1, $\frac{8}{3}$, $\frac{8}{3}$	$\theta = 149^\circ\ 12'$	$\theta' = 30^\circ\ 48'$.
For the form 1, 3, 3	$\theta = 148^\circ\ 31'$	$\theta' = 31^\circ\ 29'$.
For the form 1, 4, 4	$\theta = 146^\circ\ 27'$	$\theta' = 33^\circ\ 33'$.
For the form 1, 10, 10	$\theta = 140^\circ\ 22'$	$\theta' = 39^\circ\ 38'$.
For the form 1, 12, 12	$\theta = 139^\circ\ 32'$	$\theta' = 40^\circ\ 28'$.
For the form 1, 16, 16	$\theta = 138^\circ\ 27'$	$\theta' = 41^\circ\ 33'$.
For the form 1, 40, 40	$\theta = 136^\circ\ 25'$	$\theta' = 43^\circ\ 35'$.

Combination of the Rhombic Dodecahedron and Four-faced Cube.—When the faces $r_1\ r_4\ r_5$, &c. (Fig. 82), of the rhombic dodecahedron predominate, each four-faced solid angle of the rhombic dodecahedron is replaced by a four-faced solid angle of the four-faced cube.

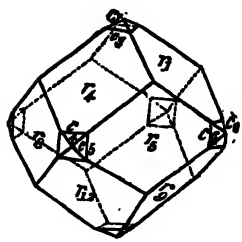


Fig. 82.

When the faces of the four-faced cube $c_1\ c_3\ c_4\ c_5$, &c. (Fig. 83), predominate, the edges of the four-faced cube which join its three-faced solid angles are replaced by planes of the rhombic dodecahedron $r_1\ r_4\ r_5$, &c.

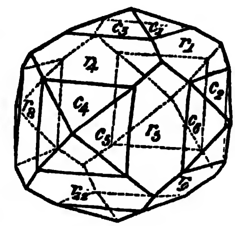


Fig. 83.

If 1, m, ∞ be the symbol of the four-faced cube, θ the inclination of c_3 or c_4 to r_4, or of c_1 or c_2 to r_1, &c., θ' that of their normals,

$$\text{Cos. } \theta = \frac{1 + \frac{1}{m}}{\sqrt{2\left(1 + \frac{1}{m^2}\right)}} \quad \theta' = 180^\circ - \theta.$$

For the form 1, $\frac{5}{4}$, ∞	$\theta = 173^\circ\ 40'$	$\theta' = 6^\circ\ 20'$
For the form 1, $\frac{4}{3}$, ∞	$\theta = 171^\circ\ 52'$	$\theta' = 8^\circ\ 8'$
For the form 1, $\frac{3}{2}$, ∞	$\theta = 168^\circ\ 41'$	$\theta' = 11^\circ\ 19'$
For the form 1, 2, ∞	$\theta = 161^\circ\ 34'$	$\theta' = 18^\circ\ 26'$
For the form 1, $\frac{5}{2}$, ∞	$\theta = 156^\circ\ 48'$	$\theta' = 23^\circ\ 12'$
For the form 1, 3, ∞	$\theta = 153^\circ\ 26'$	$\theta' = 26^\circ\ 34'$
For the form 1, 4, ∞	$\theta = 149^\circ\ 2'$	$\theta' = 30^\circ\ 58'$
For the form 1, 5, ∞	$\theta = 146^\circ\ 19'$	$\theta' = 33^\circ\ 41'$

Combination of the Rhombic Dodecahedron and Six-faced Octahedron.—When the symbol of the six-faced octahedron is 1, m, n, and the form such that $mn = m + n$. If the faces of the rhombic dodecahedron $r_1\ r_4\ r_5$, &c. (Fig. 84), predominate, the edges of the rhombic dodecahedron are replaced or bevelled by two planes of the six-faced octahedron.

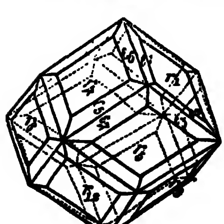


Fig. 84.

When the faces $e_1\ e_2\ e_4$, &c., of the six-faced octahedron (Fig. 85), predominate, each four-faced solid angle of the six-faced octahedron is replaced by a plane of the rhombic dodecahedron.

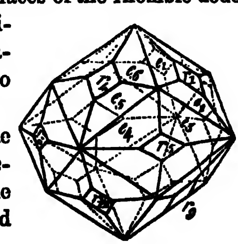


Fig. 85.

When mn is greater than $m + n$, the four-faced solid angles of the rhombic dodecahedron are replaced by the eight-faced solid angles of the octahedron.

When mn is less than $m + n$, the three-faced solid angles of the rhombic dodecahedron are replaced by the six-faced solid angles of the six-faced octahedron.

If 1, m, n be the symbol of the six-faced octahedron, θ the inclination of r_1 to e_1 or e_2, or of r_1 to e_5 or e_6, &c., θ' that of their normals,

$$\cos.\,\theta = \frac{1+{}^{1}}{\sqrt{2\left(1+\frac{1}{m^2}+\frac{1}{n^2}\right)}} \qquad \theta' = 180 - \theta.$$

For the form 1, $\frac{5}{4}$, $\frac{5}{3}$	$\theta = 153^\circ\ 56'$	$\theta' = 26^\circ\ \ 4'$
For the form 1, $\frac{64}{63}$, 64	$\theta = 179^\circ\ 13'$	$\theta' = \ \ 0^\circ\ 47'$
For the form 1, $\frac{4}{3}$, 2	$\theta = 156^\circ\ 48'$	$\theta' = 23^\circ\ 12'$.
For the form 1, $\frac{15}{11}$, $\frac{15}{7}$.	$\theta = 157^\circ\ 40'$	$\theta' = 22^\circ\ 20'$.
For the form 1, $\frac{4}{3}$, 4	$\theta = 166^\circ\ \ 6'$	$\theta' = 13^\circ\ 54'$
For the form 1, $\frac{3}{2}$, 3	$\theta = 160^\circ\ 54'$	$\theta' = 19^\circ\ \ 6'$.
For the form 1, $\frac{5}{3}$, 5	$\theta = 162^\circ\ 59'$	$\theta' = 17^\circ\ \ 1'$
For the form 1, 2, 4	$\theta = 157^\circ\ 47'$	$\theta' = 22^\circ\ 13'$
For the form 1, $\frac{11}{5}$, $\frac{11}{3}$	$\theta = 155^\circ\ 20'$	$\theta' = 24^\circ\ 40'$.
For the form 1, $\frac{16}{7}$, 4	$\theta = 155^\circ\ 12'$	$\theta' = 24^\circ\ 48'$.
For the form 1, $\frac{7}{5}$, 7	$\theta = 157^\circ\ \ 1'$	$\theta' = 22^\circ\ 59'$.
For the form 1, 4, 8	$\theta = 148^\circ\ 21'$	$\theta' = 31^\circ\ 39'$.

Complicated Combinations of the Forms of the Cubical System.—Instances of more complicated combinations of the forms of the cubical system than those already given frequently occur; but a diligent study of the simple ones, already given, will enable us to determine readily to what form each face of the crystal should be referred. The determination of the forms to which the faces of a crystal are parallel, is technically termed "reading a crystal;" the particular species to which each form belongs is generally found by measurement of the angles with a goniometer. Many species, however, may be recognised by observing the parallelism of the edges of the faces to one another, according to what is called the *zone theory*. This will be described hereafter.

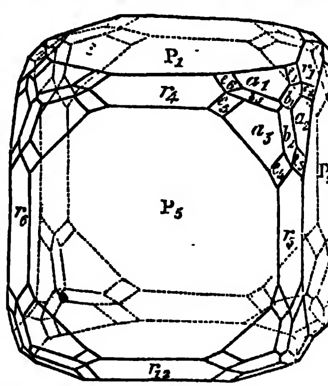


Fig. 86.

We have already given an instance of a complicated combination of forms in a crystal of Fluor spar.

The simple combinations of forms already given enable us to read this crystal with ease, and show that the faces P_1, P_2, P_5, &c., are faces of the cube; r_1 r_2, &c., r_{12}, those of the rhombic dodecahedron; a_1 a_2 and a_3, are faces of the twenty-four-faced trapezohedron; b_1 b_2 and b_3 of a three-faced cube; and e_1 e_2 e_3, &c., e_6 the faces of a six-faced octahedron.

It requires, however, actual measurement of the inclination of the faces to determine the particular species of the last three forms.

In some works on Mineralogy, as, for instance, the early editions of Phillips's "Mineralogy," the inclinations only of such faces are given without any reference to their symbols; in other works, such as the elaborate description of Mr. Turner's collection,

by Levy, from which Fig. 86 is taken, the faces are indicated only by their symbols, and the angles are not given.

The tables annexed to the previously described simple combinations will afford the student a ready means of recognising the species of the forms from the angular measurements given by Phillips; or of supplying those measurements to the crystals described by Levy.

The faces a_1 a_2 a_3, are marked a^3 in Levy's figure; hence, they are faces of a twenty-four-faced trapezohedron, whose symbol is 133 (see symbols of this figure, p. 305).

The faces b_1 b_2 b_3 are marked $a^{\frac{1}{2}}$ in Levy; they are faces of a three-faced octahedron, whose symbol is 112. The faces e_1 e_2 e_3 e_4 e_5 e_6 are marked $i = b^1\, b^{\frac{1}{2}}\, b^{\frac{1}{4}}$, and are faces of a six-faced octahedron, whose symbol is 1, 2, 4 (see p. 315).

The inclination of the face P_5 to any of the faces r_4 r_5 r_6 or r_{12}, is 135° (p. 316).

The inclination of P_5 to a_3 is 154° 46′, and of P_5 to a_1 or a_2, 107° 33′ (p. 317).

The inclination P_5 to b_2 or b_3 is 131° 49′, and of P_5 to b_1, is 109° 29′ (p. 316).

The inclination of P_5 to e_4 or e_5 is 150° 48′, to e_3 or e_6 is 115° 53′, and to e_1 or e_2, 102° 36′ (p. 319).

The inclination of r_4 to e_5 or e_6, or of r_5 to e_4 or e_3, is 157° 47′ (p. 325).

The above is sufficient to show how the inclinations of the faces of a crystal to each other may be determined from a knowledge of their symbols.

Sphere of Projection.—If we suppose the cube in which each of the forms of the cubical system have been inscribed, placed in a sphere, whose centre shall coincide with the centre of the cube; then, if lines be drawn perpendicular to the faces of each form from the centre of the sphere, and produced till they cut the surface of the sphere; the points where they cut the sphere will serve as indications of the faces to which they are perpendicular, or to which, in mathematical language, they are the normals. These points are called the *poles* of the faces of the crystal to which they are perpendicular. A map of all the forms which we have hitherto described may thus be indicated on a globe; and since the inclination of the normals to any two planes is always the inclination of the faces, less 180°; a globe, with the poles of the faces of all the forms of a crystalline substance described on it, will enable us speedily to determine the inclination of any one face to another, by simply measuring the distance between their poles, and subtracting this from 180°.

This method of mapping crystals was invented by Professor Neumann, of Königsberg.

Zones.—In the combinations of crystals, it frequently occurs that some edges are parallel to one another; instances of this will be seen in Figs. 58, 59, 64, 65, 70, 71, and many others. The poles of the faces, whose intersections are parallel to each other, all lie in a great circle of the sphere of projection—a great circle being the intersection of a plane passing through the centre of the sphere and its surface. When three or more faces of a crystal have their poles in the same *great circle*, they are said to form a *zone*, and the *great circle* is called a *zone circle*.

Maps of Crystals.—A map may be drawn on a plane surface, representing the sphere of projection, with the poles of all the faces of a crystal. Such maps, when understood, convey to the mind a vast degree of information relative to the inclinations of the faces, which could not otherwise be represented, solve many problems in crystallography, and exhibit the position of the most important zones. Professor Miller, of Cambridge, has inserted an exceedingly valuable series of these maps of crystals in

the last edition of Phillips's mineralogy. The authors of the present treatise take this opportunity of expressing their obligation to Professor Miller's work, to which they would beg to refer all those who would wish to master the science of crystallography.

The *stereographic* projection of the sphere, in which the eye of the observer is supposed to be placed on the surface of the sphere in the pole of the great circle upon which the sphere is projected, is that generally made use of for these maps. It possesses this advantage: all circles on the sphere are represented on the map by straight lines or arcs of circles.

Map of the principal Zones of the Cubical System.—With P_1 as a centre, and a radius $P_1 P_2$ of any convenient length, describe a circle $P_2 P_3 P_4 P_5$.

Through P_1 draw the diameters $P_3 P_5$ and $P_2 P_4$ perpendicular to each other.

With P_5 as a centre, and radius equal $P_5 P_2$, or $P_5 P_4$, describe the arc $P_4 r_2 P_2$, cutting $P_3 P_1$ in r_2.

With P_3, P_2 and P_4 as centres, and radii equal to the former, describe similar arcs, cutting $P_1 P_5$ in r_4, $P_1 P_4$ in r_3, and $P_1 P_2$ in r_1.

Let O_1 O_2 O_3 O_4 be the points where these arcs intersect each other.

Join $P_1 O_1$, $P_1 O_2$, $P_1 O_3$, $P_1 O_4$, and produce them to cut the circle $P_2 P_3 P_4$ in the points r_5 r_6 r_7 and r_8.

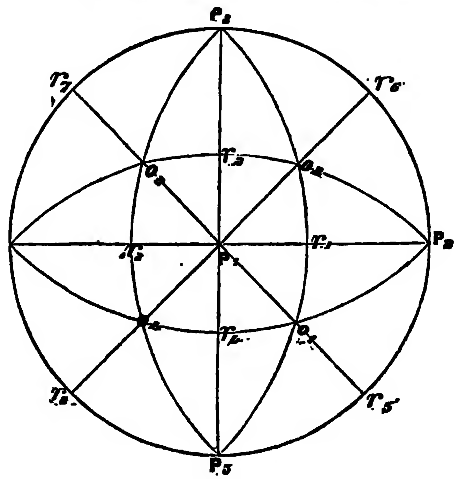


Fig. 87

Figure 87, thus described, is an orthographic projection of the sphere, representing a hemisphere with the principal zone circles of the cubical system.

P_1, P_2, P_3, P_4, and P_5, are the poles of the faces of the cube, indicated by the same letters in the preceding figures; o_1 o_2 o_3 o_4 the poles of the octahedron; r_1 r_2 r_8 the poles of the faces of the rhombic dodecahedron. $P_1 r_4$ $r_1 P_2$, $P_2 r_5$, and the similar lines and arcs, represent arcs of great circles 45° in length.

If the north pole on a globe be chosen as the pole of P_1, the equator will represent the circle $P_2 P_3 P_4$. Let P_2 be the point where the first meridian of longitude, $P_1 P_2$, cuts the equator; then P_4 will be the point where the meridian of 180°, and P_3 and P_5, the points where the meridians of 90° east and west longitude, cut the equator.

Let r_1 r_2 r_3 r_4 be the points where the circle of latitude of 45° cuts these meridians; r_5 r_6 r_7 r_8 points in the equator equidistant from P_2 P_5, &c. Draw great circles passing through $P_1 r_3$, $P_5 r_1$, $P_2 r_4$ intersecting in o_1, and similar circles for the other octants of the sphere, and the map Fig. 87 will be described on the globe. If such a map be thus delineated on a black globe, or one of slate, an approximation to the angles given in the description of the faces and their combinations, in the previous part of this treatise, may be made,—particularly when the poles of other forms are marked on the globe by methods which will be presently described. The arc $P_1 P_2$, measured by the brazen meridian, or by the flexible brass meridian usually sold with globes, will give the inclination of two adjacent faces of the cube; the distance between r_1 and r_4, similarly measured, the inclination of the normals of two adjacent faces of the

rhombic dodecahedron; $o_1\ o_2$ that of the normals, of adjacent faces of the octahedron; $P_1\ o_1$ of the normals of the faces of the cube to that of the octahedron, represented by those letters; $r_1\ o_1$ of the rhombic dodecahedron to the octahedron; and so on.

The great circles represented in Fig. 87 by the lines $P_2\ P_4$ and $P_3\ P_5$, and by the circle $P_2\ P_3\ P_4$, are the zones in which the poles of the *four-faced cube* always lie, one pole lying in each of the arcs represented by the letters P and r, and at the same distance from P in each arc.

The poles of the *four-faced cube* lie, therefore, in the zone circle passing through the poles of the cube and rhombic dodecahedron.

The poles of the *twenty-four-faced trapezohedron* always lie in one of the arcs terminated by the letters P and o, one in each. Thus one pole will lie in $P_1\ o_1$, one in $P_2\ o_1$, one in $o_1\ P_5$, &c., and each pole will be at the same angular distance in those arcs from $P_1\ P_2\ P_5$, &c.

The poles of the *three-faced octahedron* always lie in the arcs terminated by the letters o and r, one in each. The poles, therefore, of every form of the twenty-four-faced trapezohedron and three-faced octahedron lie in zones, which pass through poles of the cube octahedron and rhombic dodecahedron.

The poles of the *six-faced octahedron* never lie in any of the zones represented in Fig. 87. They always lie within one of the spherical triangles P o r, one in each triangle, and similar situated to its angular points.

The above facts will be seen more clearly by a reference to Figs. 89 and 90, in which the letters $a_1\ a_2\ a_3$ represent the poles of a *twenty-four-faced trapezohedron;* $b_1\ b_2\ b_3$, those of a *three-faced octahedron;* $c_1\ c_2$, &c., c_6, those of a *four-faced cube;* $e_1\ e_2\ e_3$, &c., e_6, those of a *six-faced octahedron.*

Describe a square (Fig. 88), $B_5\ B_6\ B_7\ B_8$, about the circle $P_2\ P_3\ P_4$, touching it in the points $P_2\ P_3\ P_4$ and P_5. Join $P_3\ P_5$, $P_2\ P_4$, $B_6\ B_8$, and $B_7\ B_5$; the last two cutting the circle in the points r_6, r_8, r_7 and r_5.

With B_8 as a centre and radius equal $B_8\ r_5$ or $B_8\ r_7$, describe the arc $r_7\ r_2\ r_1\ r_5$, cutting $P_1\ P_3$ in r_2, and $P_1\ P_2$ in r_1. With B_5, B_6 and B_7 as centres, and with the same radius, describe the arcs $r_8\ r_3\ r_6$, $r_7\ r_3\ r_5$, and $r_8\ r_1\ r_8$.

The points indicated by the letters P and r will represent the same poles as in Fig. 87. Each arc such as $r_7\ r_2\ r_1\ r_5$ will represent the half of a zone circle, in which all the poles of the six-faced octahedron whose symbols are of the form $1, \dfrac{n}{n-1}$, n will lie.

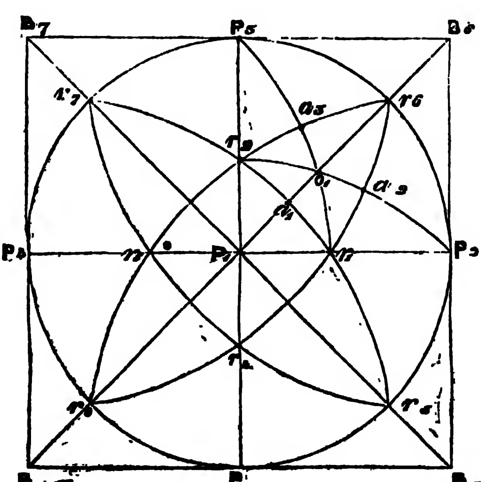


Fig. 88.

The six-faced octahedrons 1, $\frac{3}{2}$, 3; 1, $\frac{4}{3}$, 4; and 1, $\frac{64}{63}$, 64, fulfil this condition.

When we meet with the edges of the rhombic dodecahedron bevelled by planes of

the six-faced octahedron, as shown in Fig. 84; we know that the poles of the six-faced octahedron lie in this zone, and must have its symbol of the form $1, \frac{n}{n-1}, n$.

Draw the arcs $P_3\, r_1$, $P_2\, r_2$, and $P_3\, r_1$, as in Fig. 88. Let a_1 be the point where $r_2\, r_1$ cuts $P_1\, r_6$, a_2 that where $r_1\, r_6$ cuts $r_2\, P_2$, and a_3 that where $r_2\, r_6$ cuts $P_3\, r_1$.

$a_1\, a_2\, a_3$ will be poles of the twenty-four-faced trapezohedron whose symbol is 1 2 2. These lie in the same zone as those of the six-faced octahedrons whose symbols are of the form $1, \frac{n}{n-1}, n$.

When, therefore, the intersections of the rhombic dodecahedron with a twenty-four-faced trapezehedron make parallel edges, as in Fig. 80, we know, without measuring its angles, that the trapezohedron is that whose symbol is 1 2 2.

To Determine the Position of the Poles of the Faces of the Different Forms of the Cubical System on the Sphere of Projection.

The Twenty-four-faced Trapezohedron.—The angles marked θ' under the article "Combination of Cube and Twenty-four-faced Trapezohedron," page 317, will give the circle of latitude which will cut the zone $P_1\, r_6$ in a_1 (Fig. 89) for each form of the trapezohedron, and the angle ϕ' the circle of latitude, which will cut the zones $P_2\, r_2$, and $P_3\, r_1$, in a_2 and a_3, reckoning each circle of latitude from P_1 as the north pole. Thus, for the form 1, 2, 2, a_1 is the point where the circle of latitude 35° 16′ cuts $P_1\, r_6$, and a_2 and a_3 the points where the circle of latitude 65° 54′ cuts $r_2\, P_2$ and $r_1\, P_3$.

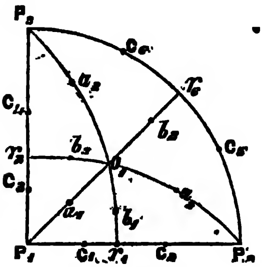


Fig. 89.

Three poles may be similarly described in each of the other octants of the sphere, and thus the poles of the twenty-four faces of the trapezohedron may be placed on the *sphere of projection.*

The Three-faced Octahedron.—Under the article "Combination of Cube and Three-faced Octahedron," page 316, θ' gives the circle of latitude for each particular form of the three-faced octahedron which cuts the zones $r_1\, P_3$, and $r_2\, P_2$, in the poles b_1 and b_3, ϕ' the circle of latitude which cuts the zone $P_1\, r_6$ in b_2.

By means of the angles θ and ϕ', the poles of all the known forms of the three-faced octahedron may be fixed on the *sphere of projection.*

The Four-faced Cube.—Under the article "Combination of Cube and Four-faced Cube," page 318, θ' gives the circle of latitude which cuts the zones $P_1\, P_2$ and $P_1\, P_3$ in the poles of the four-faced cube c_1 and c_3, and ϕ' the circle of latitude which cuts the same zones in the poles c_2 and c_4; the poles c_5 and c_6 are distant from P_2 and P_3 respectively θ' degrees in the zone $P_2\, P_3$.

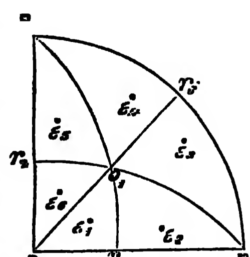


Fig. 90.

We can thus determine the position of the poles of all the known forms of the four-faced cube on the sphere of projection.

The Six-faced Octahedron.—The following table will enable us to fix the poles of the six-faced octahedron on the sphere of projection, considering P_1 (Fig. 90) as the north pole, $P_1\, P_2$ the first meridian of longitude, and $P_2\, P_3$ the equator :—

For the form 1, $\frac{5}{4}$, $\frac{5}{3}$. Latitude of pole $e_1 = 45°$.
Longitude of $e_1 = 36° 52'$.
Latitude of pole $e_2 = 55° 33'$.
Longitude of $e_2 = 30° 58'$.
Latitude of pole $e_3 = 64° 54'$.
Longitude of $e_3 = 38° 39'$.

For the form 1, $\frac{64}{63}$, 64,	Lat. $e_1 = 44° 33'$.	Lat. $e_2 = 45° 27'$.	Lat. $e_3 = 89° 22'$.
	Lon. $e_1 = 0° 55'$.	Lon. $e_2 = 0° 54'$	Lon. $e_3 = 44° 33'$.
For the form 1, $\frac{4}{3}$, 2,	Lat. $e_1 = 42° 2'$.	Lat. $e_2 = 56° 9'$.	Lat. $e_3 = 68° 12'$.
	Lon. $e_1 = 33° 41$.	Lon. $e_2 = 26° 34'$.	Lon. $e_3 = 36° 52'$.
For the form 1, $\frac{15}{11}$, $\frac{15}{7}$,	Lat. $e_1 = 41° 0'$.	Lat. $e_2 = 56° 24'$.	Lat. $e_3 = 69° 23'$.
	Lon. $e_1 = 32° 28'$.	Lon. $e_2 = 25° 1'$.	Lon. $e_3 = 36° 15'$.
For the form 1, $\frac{4}{3}$, 4,	Lat. $e_1 = 38° 20'$.	Lat. $e_2 = 53° 58'$.	Lat. $e_3 = 78° 41'$.
	Lon. $e_1 = 18° 26'$.	Lon. $e_2 = 14° 2'$.	Lon. $e_3 = 36° 52'$.
For the form 1, $\frac{3}{2}$, 3,	Lat. $e_1 = 36° 42'$.	Lat. $e_2 = 57° 41'$.	Lat. $e_3 = 74° 30'$.
	Lon. $e_1 = 26° 34'$.	Lon. $e_2 = 18° 26'$.	Lon. $e_3 = 33° 41'$.
For the form 1, $\frac{5}{3}$, 5,	Lat. $e_1 = 32° 19'$.	Lat. $e_2 = 59° 32'$.	Lat. $e_3 = 80° 16'$.
	Lon. $e_1 = 18° 26'$.	Lon. $e_2 = 11° 19'$.	Lon. $e_3 = 30° 58'$.
For the form 1, 2, 4,	Lat. $e_1 = 29° 12'$.	Lat. $e_2 = 64° 7'$.	Lat. $e_3 = 77° 24'$.
	Lon. $e_1 = 26° 34'$.	Lon. $e_2 = 14° 2'$.	Lon. $e_3 = 26° 34'$.
For the form 1, $\frac{11}{5}$, $\frac{11}{3}$,	Lat. $e_1 = 27° 56'$.	Lat. $e_2 = 66° 19'$.	Lat. $e_3 = 76° 3'$.
	Lon. $e_1 = 30° 58'$.	Lon. $e_2 = 15° 15'$.	Lon. $e_3 = 24° 26'$.
For the form 1, $\frac{16}{7}$, 4,	Lat. $e_1 = 25° 45'$.	Lat. $e_2 = 67° 00'$.	Lat. $e_3 = 77° 6'$.
	Lon. $e_1 = 29° 45'$.	Lon. $e_2 = 14° 2'$.	Lon. $e_3 = 23° 38'$.
For the form 1, $\frac{7}{3}$, 7,	Lat. $e_1 = 24° 19'$.	Lat. $e_2 = 67° 1'$.	Lat. $e_3 = 82° 31'$.
	Lon. $e_1 = 18° 26'$.	Lon. $e_2 = 8° 8'$.	Lon. $e_3 = 23° 12'$.
For the form 1, 4, 8,	Lat. $e_1 = 15° 37'$.	Lat. $e_2 = 76° 4'$.	Lat. $e_3 = 83° 5'$.
	Lon. $e_1 = 26° 34'$.	Lon. $e_2 = 6° 23'$.	Lon. $e_3 = 14° 2'$.

The latitudes of the poles e_6 e_5 and e_4 (Fig. 90) are the same respectively as those of e_1 e_2 and e_3; and the longitudes of e_6 e_5 and e_4 are respectively 45° greater than those of e_1 e_2 and e_3.

Hemihedral Forms of the Cubical System.—It has been already observed (page 294) that, with the exception of the cube and rhombic dodecahedron, another series of forms may be derived from the forms of the cubical system which we have described, by producing half their faces to meet one another after certain laws. These forms, from the method of their derivation, are called *hemihedral*, or half-faced. We shall proceed to describe them.

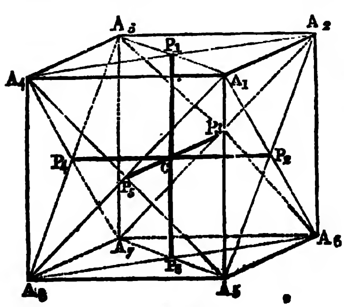


Fig. 91.

The Tetrahedron.—If we describe a cube (Fig. 91) as directed in page 296, the figure whose outline is bounded by the lines A_4 A_2, A_4 A_5, A_4 A_7, A_2 A_7, A_2 A_5, (Fig. 92) A_5 A_7, will be a tetrahedron, formed by the development of the faces of the octahedron opposite to the angular points A_1 A_3 A_6 and A_8 of the cube. This is called the *positive tetrahedron.* Another tetrahedron, A_1 A_3 A_8 A_6 (Fig. 93) may be formed by the development of the

faces of the octahedron opposite to the angular points A_2 A_4 A_5 and A_7 of the cube. This tetrahedron is precisely similar to the former in magnitude, but differs

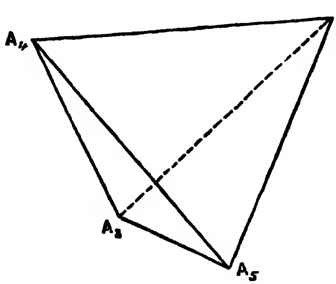


Fig. 92.

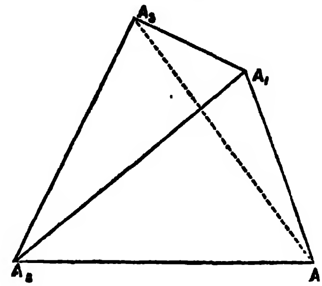


Fig. 93.

from it in its position with regard to the cube in which is is inscribed. It is called the *negative tetrahedron.* With some forms, the combinations of the *positive tetrahedron* are different from those of the *negative* tetrahedron.

Faces, Angles, Edges, &c.—The *tetrahedron* is bounded by four similar and equal plane faces, such as A_1 A_8 A_6 (Fig. 93), each of which is an equilateral triangle. It has four *three-faced solid angles,* which touch the alternate three-faced solid angles of the cube in which it is inscribed; *six equal edges,* one of which corresponds with one diagonal of the face of the cube, for every face; the *cubical axes* join the centres of the opposite edges; one half of each *octrahedral axis* coincides with that of the cube, while the other half is cut by a face of the tetrahedron at a third of its distance from the centre. The adjacent faces of the tetrahedron are inclined to each other at an angle of 70° 32′, and their normals consequently at an angle of 109° 28′.

Symbols.—The symbol for this form is $\frac{111}{2}$. Naumann's symbol for the tetrahedron is $\frac{O}{2}$; Miller's, κ 111; frequently the same symbol is used as for the octahedron, only intimating that it is a hemihedral form.

To describe a net for the Tetrahedron which may be inscribed in a given cube.

Draw a line A_4 A_5 (Fig. 94) equal to the line A_4 A_5 (Fig. 91); on this describe an

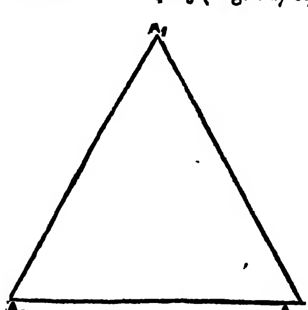


Fig. 94.

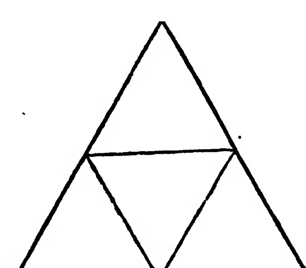


Fig. 95.

equilateral triangle A_1 A_4 A_5. This will give a face of the tetrahedron.

Four such faces, arranged as in Fig. 95, will form the required net.

Crystals of the following minerals have faces parallel to the Tetrahedron.

Blende (sulphuret of zinc).	Eulytine (bismuth blende).	Rhodizite.
Boracite.	Fahlerz (gray copper).	Tennantite.
Diamond.	Pharmacosiderite (arseniate of iron).	Tritonite.

Twelve-faced Trapezohedron.—The *twelve-faced trapezohedron* is the hemihedral form of the *three-faced octahedron.* It has been called also the *deltoidal*, or the *trapezoidal dodecahedron.*

As there are two tetrahedrons, one positive and the other negative, so there are two twelve-faced trapezohedrons—the positive one, Fig. 96, and the negative, Fig. 97.

The positive trapezohedron is formed by the development of the faces of the three-faced octahedron, forming its three-faced solid angles opposite to the edges A_1 A_3 A_6 and A_8 of the cube (Fig. 34, p. 303); the negative trapezohedron by the development of the solid angles opposite to the edges A_2 A_4 A_5 and A_7 of the cube (Fig. 34).

These trapezohedrons are in all respects similar to each other, except in their position with respect to their circumscribing cube, and their combinations with other forms.

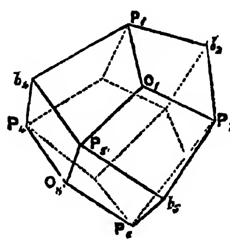


Fig. 96.

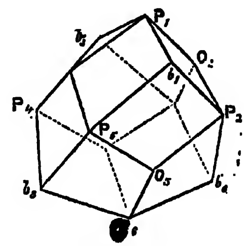


Fig. 97.

Faces, Angles, Edges.—The *twelve-faced trapezohedron* is bounded by *twelve* similar and equal trapeziums, such as b_4 P_1 O_1 P_5 (Fig. 96), having the edge P_1 b_4 equal P_5 b_4, and O_1 P_5 equal O_1 P_1. It has four *three-faced solid angles* which always lie in the octahedral axes of the cube, such as O_1, O_3, O_8, O_6 (Fig. 96), four *three-faced solid angles* b_2, b_4, b_5, b_7 (Fig. 96), more acute than the former, which lie on opposite sides of the same octahedral axes; and six *four-faced solid angles*, which always lie in the extremities of the cubical axes P_1 P_2 P_4 &c. (Fig. 96). There are twelve shorter edges joining the solid angles marked P and O, and twelve longer joining the solid angles indicated by P and B.

Symbols.—The symbol for this form is $\frac{11m}{2}$; Naumann's is $\frac{nO}{2}$; Miller's $\kappa.hhk$.

To draw the Twelve-faced Trapezohedron.—Make the same construction as for Fig. 33, page 303, and add the following, as in Fig. 98.

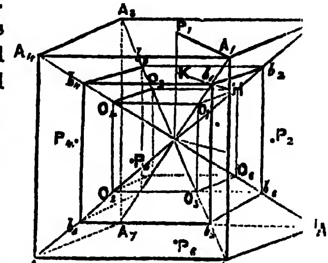


Fig. 98.

The letters B_3 and C have been omitted in Fig. 98; they may easily be supplied by a reference to Fig. 33.

In $B_5 A_1$ take a point H, such that $B_5 H = \frac{1}{2 - \frac{1}{n}} B_5 A_1$.

Thus if $n = 2$ $B_5 H = \frac{1}{2 - \frac{1}{2}} B_5 A_1 = \frac{2}{3} B_5 A_1$.

Take C K in C P_1 equal to B_5 H. Join H K_1 cutting A_1 C in b_1.

Through b_1 draw $b_1 b_2$ parallel to $A_1 A_2$ cutting C A_2 in b_2, and $b_1 b_4$ parallel to $A_1 A_4$ cutting C A_4 in b_4; and so on till the cube $b_1 b_2 b_3$, &c. b_8, is described as shown in Fig. 98.

Joining the points P_1, P_2, &c., P_6, $O_1 O_8$, &c., $b_2 b_4$, &c., as in Fig. 96, the positive trapezohedron will be described; and joining $P_1 P_2$, &c., P_6, $O_2 O_4$, &c., $b_1 b_3$, &c., as in Fig. 97, the negative trapezohedron.

Axes.—The cubical axes terminate the opposite four-faced solid angles, and coincide with those of the cube. One half of each octahedral axis is cut by a three-faced solid angle at a distance $C O_1 = \frac{1}{2 + \frac{1}{n}}$ from the centre C, and the other half by the other three-faced solid angle at a distance $C b = \frac{1}{2 - \frac{1}{n}}$ from C.

As n varies from 1 when this form coincides with tetrahedron to ∞ when it coincides with the rhombic dodecahedron, C O increases from a $\frac{1}{3}$rd to $\frac{1}{2}$ of C A, and C b diminishes from C A to $\frac{1}{2}$ C A.

Inclination of Faces of the Twelve-faced Trapezohedron.—If θ be the angle of inclination of two adjacent faces, over an edge P b, and ϕ the angle over the shorter edge P O,

$$\cos.\ \theta = \frac{n\,(n-2)}{2\,n^2 + 1} \qquad \cos.\ \phi = \frac{n\,(n+2)}{2\,n^2+1}$$

To Describe a Net for the Twelve-faced Trapezohedron, which may be inscribed in a given Cube.

Describe the figure $A_1 P_1 C B_5$ (Fig. 99) the same as $A_1 P_1 C B_5$ (Fig. 35) page 303.

Take C K and H B_5, both $= \frac{1}{2 - \frac{1}{n}} C P_1$.

Join A_1 C and H K, cutting in b and then join P_1 b.

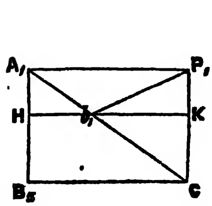


Fig. 99.

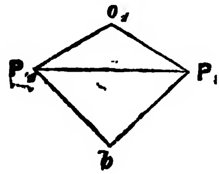


Fig. 100.

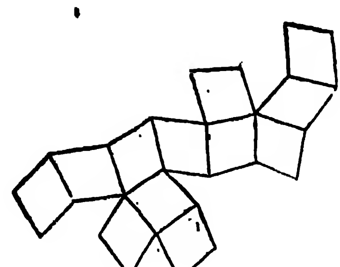


Fig. 101.

Let $P_1 O_1 P_2$ (Fig. 100) be the same triangle as $P_1 O_1 P_2$, Fig. 36, page 304.

On $P_1 P_2$ as a base describe an isosceles triangle P_1 b P_2 (Fig. 100), having each of its sides $P_1 b_8$, $P_2 b$, equal P_1 b, Fig. 99.

Twelve such figures as $O_1\ P_1\ b\ P_2$, arranged as in Fig. 101, will give the required net.

Forms of the Twelve-faced Trapezohedron.—The form $\frac{112}{2}\ \frac{20}{2}$ Naumann; κ. 122 Miller; has CO $= \frac{2}{5}$ CA, and C$b = \frac{2}{3}$ CA. Inclination of faces over Pb 90', that of their normals 90°; over the edge PO 152° 44′, that of their normals 27° 16′.

Faces of this form occur in Blende, Diamond, and Pharmacosiderite.

The form $\frac{11\frac{3}{2}}{2}, \frac{\frac{3}{2}0}{2}$ Naumann; κ.233 Miller; has CO $= \frac{3}{8}$ CA and C$b = \frac{3}{4}$ CA. Inclination of faces over the edge Pb 82° 9′, that of their normals 97° 51′; over the edge PO 162° 40′, that of their normals 17° 20′.

Faces of this form have been observed in Fahlerz.

The Three-Faced Tetrahedron.—The *three-faced tetrahedron* has three faces corresponding to each face of the regular tetrahedron; it is called also the *trigonal dodecahedron*, *triakistetrahedron*, *pyramidal tetrahedron*, and by Haidinger *kuproid*.

This form is derived from the *twenty-four-faced trapezohedron* by the development of half its faces. The faces forming the three-faced solid angles $O_1\ O_8$, &c., opposite the solid angles $A_1\ A_3\ A_6$ and A_8 of the cube (Fig. 39, p. 305), producing the *positive*

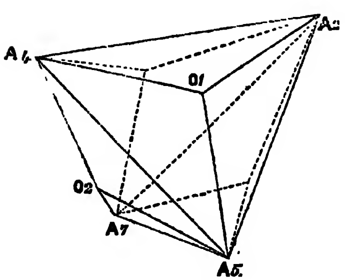


Fig. 102.

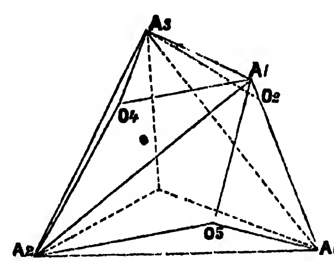


Fig. 103.

three-faced tetrahedron $A_2\ A_4\ A_5\ A_7$ (Fig. 102); and those opposite the solid angles A_2 $A_4\ A_7$ and A_5 (Fig. 39), the *negative three-faced tetrahedron* $A_1\ A_3\ A_8\ A_6$ (Fig. 103.)

These three-faced tetrahedrons are, in all respects, similar, except in their position and consequent modification of their combinations with other forms.

Faces, Angles, and Edges—The *three-faced tetrahedron* is bounded by twelve equal and similar isosceles triangles. It has *four three-faced solid angles*, $O_1\ O_2$ &c., opposite the alternate three-faced solid angles of the cube in which it is inscribed, and four *six-faced solid angles* $A_2\ A_4$ &c., which touch the other alternate three-faced solid angles of the cube. The edges are *twelve shorter* AO, AO, &c., joining the three-faced and six-faced solid angles, and *six longer* AA, AA &c., each lying along a diagonal of a face of the cube, and joining the six-faced solid angles together.

Symbols.—The symbol for the *three-faced tetrahedron* is $\frac{1mm}{2}$; Naumann's is $\frac{mOm}{2}$; and Miller's $\kappa.hhk$.

To draw the Three-faced Tetrahedron.—Describe the same figure as directed (Fig. 39, p. 305), for drawing the *twenty-four-faced trapezohedron*.

Join the points $A_1\ A_4\ O_1\ A_5\ A_7$, &c., as shown in Fig. 102, for the *positive three-faced tetrahedron*, and the points $A_1\ A_3\ O_2\ O_4\ A_8\ O_5$, &c., as shown in Fig. 103, for the *negative three-faced tetrahedron*.

Axes.—The *cubical axes* join the centres of the opposite longer edges of the *three-faced tetrahedron*; one half of each octahedral axis coincides with that of the cube, and the other half, as CO is the $\frac{m}{m+2}$th part of CA.

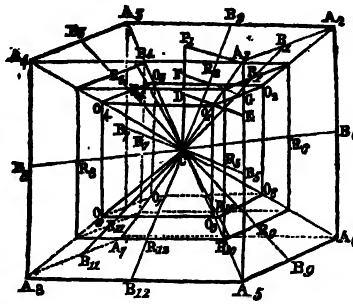


Fig. 104.

Inclination of adjacent Faces.—If θ be the angle of inclination of two faces over one of the longer edges, as $A_1\ A_3$, and ϕ over one of the shorter edges as OA,

$$\text{Cos. } \theta = \frac{m^2 - 2}{m^2 + 2} \quad \cos. \phi = \frac{2m + 1}{m^2 + 2}.$$

Limits of Form.—As m increases in value from 1 to ∞, this form varies from that of the tetrahedron to that of the cube, and CO increases from the $\frac{1}{3}$rd to the whole of CA.

To construct a Net of the Three-faced Tetrahedron which can be inscribed in a given Cube.—Draw a face $P_1\ R_4\ O_1\ R_1$ (Fig. 105), of the *twenty-four faced trapezohedron* from which the *three-faced tetrahedron* is derived, as described in Fig. 42, p. 307.

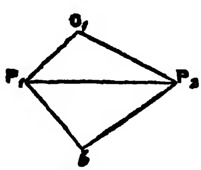


Fig. 105.

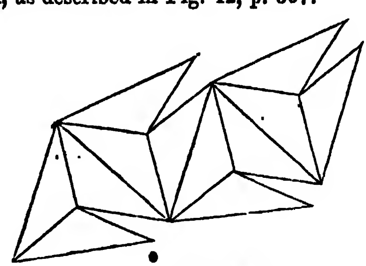


Fig. 106.

Through P_1 draw $A_4\ A_2$ perpendicular to $P_1\ O_1$.

Produce $O_1\ R_4$ to meet $P_1\ A_4$ in A_4; and $O_1\ R_1$ to meet $P_1\ A_2$ in A_2. Then the isosceles triangle $O_1\ A_4\ A_2$ will be a face of the required *three-faced tetrahedron*; and twelve such faces, arranged as in Fig. 106, will form the required net.

Forms of the Three-faced Tetrahedron.—The form $\frac{122}{2}, \frac{2O2}{2}$ Naumann, κ. 112 Miller; has CO $= \frac{1}{2}$ CA. Inclination of faces over the longer edge AA 109° 28′, that of their normals 70° 32′; over the shorter edge OA 146° 27′, normals 33° 33′

This form occurs in Boracite, Eulytine, Fahlerz, and Tennantite.

The form $\frac{133}{2}, \frac{3O3}{2}$ Naumann, κ. 113 Miller, has CO $= \frac{3}{5}$ CA. Inclination of faces over the longer edge AA 129° 31′, that of their normals 50° 29′; over the shorter edge OA 129° 31′, that of their normals 50° 29′.—This form occurs in Blende and Fahlerz.

The form $\frac{1\frac{3}{2}\frac{3}{2}}{2}, \frac{\frac{3}{2}O\frac{3}{2}}{2}$ Naumann, κ. 223 Miller, has CO $= \frac{3}{7}$ CA. Inclination of

faces over the longer edge AA, 93° 22′, that of their normals 86° 38′; over the shorter edge OA, 160° 15′, that of their normals 19° 45′.

This form occurs in Tennantite.

Six-faced Tetrahedron.—The *six-faced tetrahedron*, called also the *hexakis-tetrahedron*, and by Haidinger *boracitoid*, is a hemihedral form derived from the *six-faced octahedron*, by the development of the faces constituting four of its solid six-faced angles, opposite the alternate solid angles of the cube in which it is inscribed.

Thus, if the faces constituting the six-faced solid angles O_1 O_5 O_6 O_8, opposite the angles A_1 A_5 A_6 A_8 (Fig. 50, page 311), of the cube, be produced to meet one another, the resulting figure is the *positive six-faced tetrahedron* (Fig. 107). [If the faces of the solid

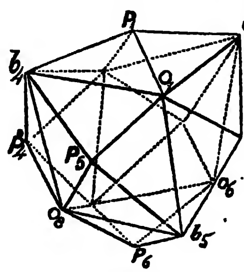


Fig. 107.

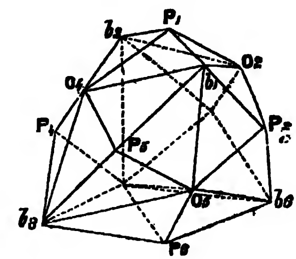


Fig. 108.

ngles O_4 O_2 O_3 O_7, opposite the angles A_2 A_4 A_3 and A_7 (Fig. 50) of the cube be produced to meet, the resulting figure will be the *negative six-faced tetrahedron* (Fig. 109).

Faces, Solid Angles, and Edges.—The *six-faced tetrahedron* is bounded by twenty-four equal and similar scalene triangles, such as P_1 O_1 b_4 (Fig. 107). It has four *six-faced solid angles* O_1 O_6, &c., which are the same as those of the *six-faced octahedron* from which it is derived; these always lie in the octahedral axis of the cube in which the figure can be inscribed. The four *six-faced solid angles* b_2 b_4, &c. more acute than the former, always lie in the octahedral axes of the cube, but on the other side of the centre of the figure from the former; thus each octahedral axis, as A_1 A_7 (Fig. 50) of the cube has one six-faced solid angle, such as O_1, on one side of its centre C, and on the other side a more acute six-faced solid angle b_7. There are six *four-faced solid angles*, P_1 P_2, &c., P_6, which terminate the cubical axes, and touch the cube in which the figure is inscribed in the centre of each face. It has twelve shorter edges joining the four-faced solid angles with the obtuse six-faced solid angles, such as P_1 O_1 (Fig. 107); twelve intermediate joining the four-faced with the acute six-faced solid angles, such as P_1 b_4; and twelve longer joining the acute and obtuse six-faced solid angles, such as O_1 b_4.

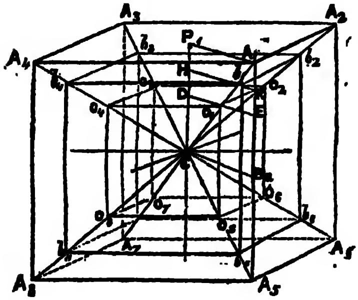


Fig. 109.

To Draw the Six-faced Tetrahedron.—Describe a cube A_1 A_2 A_3 &c., A_8 (Fig. 109); draw its octahedral axes, and in it inscribe a cube O_1 O_2 O_3 &c., O_8, as directed in Fig. 50, page 311, such that $O_1\,O_2 = \dfrac{1}{1+\frac{1}{\ }+\frac{1}{\ }}$

The letters A_1 B_5 E_1 D and P_1 having the same position in Fig. 109 that they have in Fig. 50, make the following additional construction.

In B_5 A_1 take a point K such that,

$$B_5 K = \frac{1}{1 + \frac{1}{m} - \frac{1}{n}} A_1 B_5.$$

In CP_1 take $CH = B_5 K_1$. Join HK cutting CA_1 in b_1.

Through b_1 draw $b_1 b_2$ parallel to $A_1 A_2$ and meeting CA_2 in b_2, and $b_1 b_4$ parallel to $A_1 A_4$ meeting CA_4 in b_4, and so on, till a cube $b_1 b_2 b_3$, &c., b_8 is inscribed in the cube $A_1 A_2$, &c., A_8 having Cb_1 Cb_2, &c., Cb_8 for its octahedral axes.

Join the points P_1 O_1 b_2 &c., as shown in Fig. 107, for the *positive six-faced tetrahedron*, and P_1 O_2 b_1, &c., as in Fig. 108, for the *negative six-faced tetrahedron*.

Symbols.—The symbol for the *six-faced tetrahedron* is $\frac{1\, m\, n}{2}$, Naumann's $\frac{m\,O\,n}{2}$, and Miller's $\kappa.hkl$.

Axes of the Six-faced Tetrahedron.—The *cubical axes* join the opposite four-faced solid angles, and the *octahedral axes* join the obtuse four-faced solid angles to the acute four-faced solid angles opposite to them; the former at a distance equal to the $\frac{1}{1 + \frac{1}{m} + \frac{1}{n}}$th part of the extremity of the octahedral axis from the centre, and the latter at the $\frac{1}{1 + \frac{1}{m} - \frac{1}{n}}$th part of that distance.

Inclination of the adjacent faces.—If θ be the angle of inclination of two adjacent faces over the edge PO (Figs. 107 and 168), joining the four-faced and obtuse six-faced solid angles,

$$\text{Cos. } \theta = \frac{1 + \frac{2}{mn}}{1 + \frac{1}{m^2} + \frac{1}{n^2}}$$

If ϕ be the angle of inclination over the edge Ob, joining the obtuse and acute six-faced solid angles,

$$\text{Cos. } \phi = \frac{\frac{2}{m} + \frac{1}{n^2}}{1 + \frac{1}{m^2} + \frac{1}{n^2}}$$

If ψ be the angle of inclination over the edge Pb, joining the four-faced and acute six-faced solid angles,

$$\text{Cos. } \psi = \frac{1 - \frac{2}{mn}}{1 + \frac{1}{m^2} + \frac{1}{n^2}}$$

Limits of the form of the six-faced tetrahedron.—As m and n approach in magnitude to unity, the *six-faced octahedron* approximates to the *tetrahedron;* and when m and n

are both equal to unity, it becomes the *tetrahedron*. In this case the six faces forming the obtuse six-faced solid angle, as well as the edges PO and Ob, all lie in the same plane; and the edges, such as P_1 b_1 and P_1 b_2, in the same straight line.

As m and n increase in magnitude and equality to each other, the ***six-faced tetrahedron*** approximates to the *cube*; and when m and n are both infinitely great, it coincides with it. In this case the four planes which form each four-faced solid angle lie in the same plane.

As m approaches to unity, while n increases in magnitude, the ***six-faced tetrahedron*** approximates to the ***rhombic dodecahedron***; and when m equals unity, and n is infinitely great, it becomes the ***rhombic dodecahedron***. In this case the planes on each side of the edge Ob lie in the same plane.

When m equals unity, while n remains finite, the ***six-faced tetrahedron*** becomes the ***twelve-faced trapezohedron***; and the faces on each side of the edge Ob lie in the same plane.

When m and n are equal to each other, both finite and greater than unity, the ***six-faced tetrahedron*** becomes the ***three-faced tetrahedron***, and the faces on each side of the edge PO lie in the same plane.

When m remains finite, and n becomes infinite, the ***six-faced tetrahedron*** becomes the ***four-faced cube***, and the faces each become equal and similar isosceles triangles.

From the above it will be seen that the ***cube***, ***rhombic dodecahedron***, and ***four-faced cube***, are limiting forms of the hemihedral form, the ***six-faced tetrahedron***.

To describe a Net for the Six-faced Tetrahedron which may be inscribed in a given Cube.

Draw A_1 P_1 B_5 C (Fig. 110), intersected by A_1 C and ED, meeting in O_1, as directed for Fig. 52, page 313.

$$\text{Take CH} = \frac{1}{1 + \frac{1}{m} - \frac{1}{n}} P_1 C.$$

Make B_5 K = CH. Join KH, cutting A_1 C in b_1.
Join P_1 O_1, P_1 b_1.
Produce A_1 B_5 to A_5 and P_1 C, to P_6. Make $B_5 A_5 = A_1 B_5$, $C P_6 = P_1 C$.
Take B_5 E′ = B_5 E and C D′ = C D.
Join E′ D′, A_5 P_6.

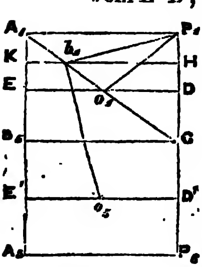


Fig. 110.

Fig. 111.

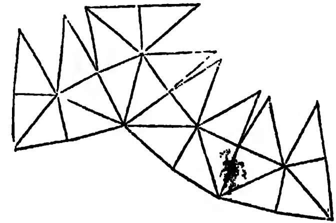


Fig. 112.

In E′ D′ take E′ O_5 = E O_1.
Join b_1 O_5,

Then Fig. 111, draw $b\,o = b_1\,O_5$ of Fig. 110, and on it describe a triangle P b o, having the side P b = P_1 b_1, and the side P O = P_1 O_1 of Fig. 110.

Then P b o (Fig. 111), is a face of the *six-faced tetrahedron* required, and twenty-four such faces arranged, as in Fig. 112, will give the required net.

Forms of the six-faced Tetrahedron.—The form $\frac{1, \frac{4}{3}, 5}{2}, \frac{5, O, \frac{5}{4}}{2}$ Naumann, and κ. 5, 3, $\bar{1}$ Miller, is the only one which has been observed in nature.

Its obtuse six-faced angles cut the octahedral axes of the cube at a distance $= \frac{4}{5}$, and its acute six-faced angles at a distance $= \frac{4}{9}$ of the centre, from the extremity of the octahedral axis.

$$\theta = 152° \; 20' \; \phi = 152° \; 20', \text{ and } \psi = 122° \; 53'.$$

Faces parallel to this form have been observed in crystals of *boracite.*

Hemihedral Forms with inclined Faces.—The preceding hemihedral forms which we have considered, may be referred to the tetrahedron as their type, and may all be derived, as we have shown, from the *six-faced tetrahedron;* none of these forms have a face parallel to any other face of the same form. There are two hemihedral forms with parallel faces.

Hemihedral Forms with Parallel Faces.—One hemihedral form with parallel faces is derived from the *four-faced cube,* and is a *twelve-faced pentagon;* the other is obtained from the *six-faced octahedron,* and is a *twenty-four faced trapezohedron.*

The Pentagonal Dodecahedron.—The *pentagonal dodecahedron,* called also the *pyritoid,* has twelve pentagonal faces, and is a hemihedral form of the *four-faced cube* derived from it, according to the following laws:

The alternate faces of each six-faced solid angle O_1 O_2 O_3, &c., O_8 (Fig. 44, page 308), of the *four-faced cube,* are produced to meet each other.

Thus the faces P_1 O_1 O_4, P_5 O_1 O_5, and P_2 O_1 O_2 (Fig. 44), of the angle O_1, and three similarly situated faces of the other six-faced solid angles, produce the *positive pentagonal*

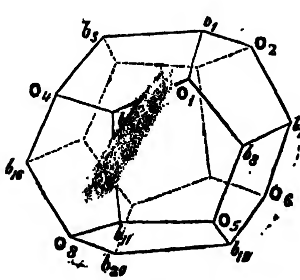


Fig. 113.

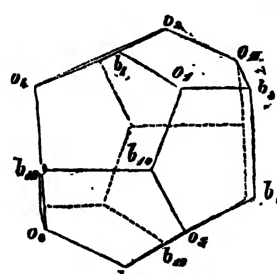


Fig. 114.

dodecahedron (Fig. 113). The remaining faces O_4 O_1 P_5, O_5 O_1 P_2, and O_2 O_1 P_1, and those similarly situated to them, produce the *negative pentagonal dodecahedron* (Fig. 114).

Faces, Solid Angles, and Edges.—This form is bounded by twelve equal and similar pentagonal faces, such as b_1 O_1 b_9 O_4 b_3 (Fig. 113). These pentagonal faces have always four of their edges equal to each other, the fifth, b_1 b_3, generally unequal to the others. The only case in which b_1 b_3 is equal to the others, is that of the *regular pentagonal dodecahedron,* which is one of the *five platonic bodies;* this form has not been observed in nature.

The *pentagonal dodecahedron* has *eight three-faced solid angles* which always lie in the octahedral axes of the cube in which it can be inscribed, O_1 O_2 &c. (Figs. 113 and 114).

And *twelve three-faced solid angles* which do not lie in any one of the three species of axes belonging to the cube. They always lie, however, in a face of the circumscribing cube. There are twenty-four edges (Ob) joining the *three-faced solid angles*, bounded by *equal plane angles* lying in the octahedral axes, with the *three-faced solid angles* bounded by *unequal plane angles*, and six edges (bb) joining the two species of *three-faced solid angles* together. These six edges (bb) always lie in a face of the circumscribing cube, in a line passing through the centre of the face parallel to one of its edges, and the cubical axes always pass through the centre of this edge.

Symbols.—The symbol for the *pentagonal dodecahedron* is $\frac{1\ m\ \infty}{2}$, Naumann's $\frac{\infty\ O\ m}{2}$, and Miller's $\pi.hko$.

To draw the Pentagonal Dodecahedron.—Prick off the points P_1 P_2, &c., P_6, B_1 B_2 B_3, &c., B_{12}, and O_1 O_2 O_3 O_4, &c., O_8, of Fig. 45, page 308.

Join P_1 P_6, P_2 P_4, and P_5 P_3.

Also B_1 B_3, B_2 B_4, B_1 B_9, B_5 B_6, &c., O_1 O_2, O_1 O_4, &c. (Fig. 115).

Along each of these lines take P_1 b_1, P_2 b_2, &c., $= (\frac{1}{m} - 1)$ P_1 B_1, $(\frac{1}{m} - 1)$ P_2 B_2, &c.

The portions b_1 B_1, b_3 B_3 are omitted in Fig. 115.

Then joining the points b_1 b_3 b_9, with O_1 O_4, b_3 b_{11} b_9, with O_5 O_1, &c., as in Fig. 113, the *positive twelve-faced pentagon* will be delineated. The *negative twelve-faced pentagon* will be drawn by joining O_1 O_2 with b_4 b_2 and b_5, and O_1 and O_5 with b_8 b_{10} and b_6, &c., as in Fig. 114.

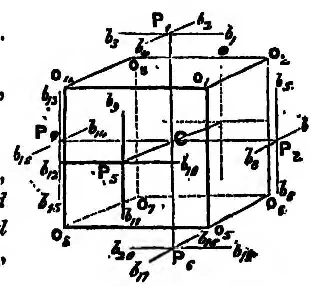


Fig. 115.

Axes.—The *cubical axes* join the centres of the opposite six unequal edges; the *octahedral axes* join the opposite three-faced solid angles contained by equal plane angles.

Inclination of Adjacent Faces.—If θ be the angle of inclination of two adjacent faces measured over the edge bb_1, and ϕ the angle of inclination of adjacent faces over the edge Ob, then

$$\text{Cos. } \theta = \frac{1 - \frac{\ }{m^2}}{1 + \frac{1}{\ }} \quad \text{and cos. } \phi = \frac{1}{1 +}$$

Limits of the Form.—As m increases from 1 to ∞, the *pentagonal dodecahedron* varies from the *rhombic dodecahedron* to the cube. The nearer the *pentagonal dodecahedron* approaches to the *rhombic dodecahedron*, or m to 1, the smaller becomes the edge $b\ b$, till, when $m = 1$, it vanishes altogether; and the greater m becomes, or the form approximates to that of the cube, the nearer the edge $b\ b$ approaches to two, or the length of the edge of the circumscribing cube.

To construct a Net of the Twelve-faced Pentagon which can be inscribed in a given Cube.—The same construction being made (Fig. 116), as directed for Fig. 46, page 309, add the following:—

Let H be the point where E O_1 cuts B_1 P_2.

Take b in B_1 P_1, so that B_1 $b = \frac{1}{m}$ B_1 P_1.

Take C L $= P_1$ b. Join b L, b P_2, the latter cutting E H in M.

Join L M. Take L S $=$ L M. Through S draw S T parallel A_1 B_3; meeting E H in T, and join b T.

Then (Fig. 117) draw P O $=$ P_1 O_1, Fig. 116. On P O describe the triangle P *b* O, having its side *b* O $=$ T *b*, Fig 116, and the side P *b* $=$ P_1 *b*, Fig. 116.

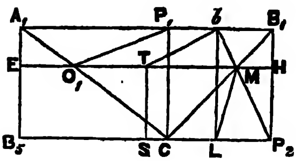


Fig. 116.

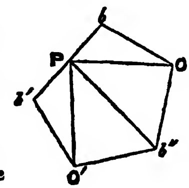


Fig. 117.

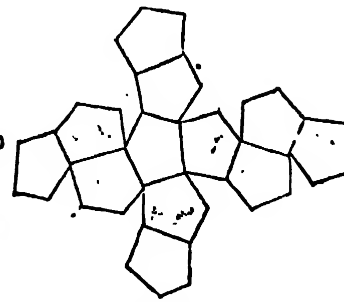


Fig. 118.

On the other side of P O (Fig 117), describe the triangle P *b''*, O having the side O *b''* $=$ T *b*, Fig. 116, and side P *b''* $=$ P_2 *b*, Fig. 116.

On the opposite side of P *b''* describe the figure P *b'* O' *b''*, similar and equal to P *b* O *b''*. Then *b' b* O *b''* O' is a face of the required form, and twelve such pentagonal faces, arranged as in Fig. 118, will give the required net.

Forms of the Pentagonal Dodecahedron.—The form $\frac{1\ 2\ \infty}{2}$, $\frac{\infty\ O\ 2}{2}$ Naumann, and π. 210 Miller, has

$$\theta = 126^\circ\ 52',\ \text{and}\ \phi = 113^\circ\ 35',$$

the angles of their normals being 53° 8′, and 66° 25′.

This form occurs in crystals of Cobaltine, Gersdorffite, and Pyrite.

The form $\frac{1\ 3\ \infty}{2}$, $\frac{\infty\ O\ 3}{2}$ Naumann, and π. 310 Miller, has

$$\theta = 143^\circ\ 8',\ \text{and}\ \phi = 107^\circ\ 27',$$

the angles of their normals being 36° 52′, and 72° 33′.

It occurs in Hauderite and Pyrite.

The form $\frac{1\ \frac{3}{2}\ \infty}{2}$ $\frac{\infty\ O\ \frac{3}{2}}{2}$ Naumann, π. 320 Miller, has

$$\theta = 112^\circ\ 37',\ \text{and}\ \phi = 117^\circ\ 29',$$

the angles of their normals being 67° 23′, and 62° 31′.

Occurs in Pyrite.

The form $\frac{1\ 4\ \infty}{2}$ $\frac{\infty\ O\ 4}{2}$ Naumann, π, 410 Miller, has

$$\theta = 151^\circ\ 56',\ \text{and}\ \phi = 103^\circ\ 37';$$

the angles of their normals being 28° 4′, and 76° 23′.

It occurs in crystals of Cobaltine.

The Irregular Twenty-four-faced Trapezohedron.—Called the *irregular twenty-four-faced trapezohedron* because its trapezoidal faces have only two edges equal to each other, and to distinguish it from the *twenty-four-faced trapezohedron*, which is a *holohedral form*, and has its four edges equal to each other in pairs. This form is called also the *Trapezoidal icositetrahedron*, the *Dyakis dodecahedron*, the *Diploid*, and the *Diplopyritoid.*

It is derived from the *six-faced octahedron* by the development of half its face according to the following law. Each alternate face of the six-faced solid angle O_1 (Fig. 49, page 311), and the similarly-situated faces of the other seven six-faced solid angles are produced, till they meet to form the *positive twenty-four-faced trapezohedron* (Fig. 119). The remaining faces, when produced, form the *negative twenty-four-faced trapezohdron* (Fig. 120).

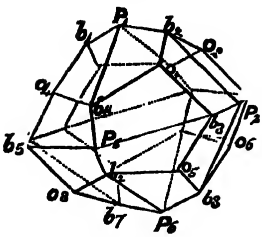


Fig. 119.

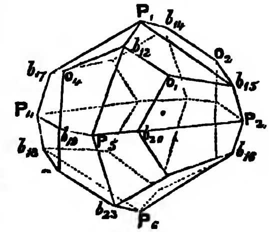


Fig. 120.

Faces, Solid Angles, and Edges.—This form is bounded by twenty-four irregular trapeziums, such as $P_1\ b_2\ o_1\ b_{11}$ (Fig. 119), having only two sides equal, as $o_1\ b_2$ and $o_1\ b_{11}$. It has *six four-faced solid angles*, such as $P_1\ P_2$, &c., P_6, which terminate the opposite extremities of the cubical axes, and touch the centre of each face of the circumscribing cube. Eight *three-faced solid angles*, $o_1\ o_2$, &c., o_8, which always lie in the octahedral axes of the circumscribing cube. Twelve *four-faced solid angles*, $b_1\ b_2$, &c., which do not lie in the cubic, octahedral, or rhombic axes of the cube. It has twelve shorter edges, $P_1\ b_1$, $P_1\ b_2$, &c.; twelve longer, $P_1\ b_{11}$, $P_6\ b_{12}$, &c.; and twenty-four intermediate edges, $o_1\ b_2$, $o_1\ b_{11}$, &c.

Symbols.—The symbol for this form is $\left[\frac{1\ m\ n}{2}\right]$. Naumann $\left[\frac{m\ O\ n}{2}\right]$, and Miller π, $h\ k\ l$.

To Draw the Irregular Twenty-four-faced Trapezohedron.—Prick off the points $P_1\ P_2$, &c., P_6, $o_1\ o_2$, &c., o_8, & C, from Fig. 51, page 312, for the Figs. 121 and 122. Join $C\ P_1\ C\ P_2$, &c., $o_1\ o_2\ o_3$, &c. In $C P_1$, $C P_2$, &c., $C P_6$, take points $e_1\ e_2$, &c., e_6 (Figs. 121 and 122), such that

$$c\ e = \frac{1 - \frac{1}{n}}{1 - \frac{1}{mn}}\ C\ P.$$

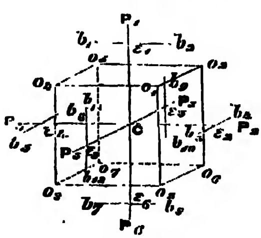


Fig. 121.

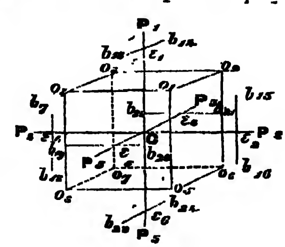


Fig. 122.

In Fig. 121, through e_1 and e_6 draw $b_1\ b_2$, and $b_7\ b_8$, parallel to C P_2; through e_2 and e_1, $b_3 b_4$, and $b_5\ b_6$, parallel to C P_3; and through e_3 and e_3, $b_{11}\ b_{12}$, and $b_9\ b_{10}$, parallel to C P_1. Also, in Fig. 122, draw $b_{13}\ b_{14}$, and $b_{23}\ b_{24}$, parallel to C P_3; b_{17} and b_{18}, and $b_{15}\ b_{16}$, parallel to C P_1; and $b_{19}\ b_{20}$, $b_{21}\ b_{22}$, parallel to C P_2.

Throughout both figures take $e\ b = \frac{1 - \frac{1}{n}}{1 - \frac{1}{mn}}$ C P, for the lines parallel C P_1 or C P_2, and half that quantity for those parallel C P_3.

Join $P_1\ o_1$, $b_2\ b_{11}$, &c., Fig. 119, for the *positive twenty-four-faced trapezohedron*, and $P_1\ b_{14}\ b_{18}\ o_1\ b_{13}$, &c., Fig. 120, for the *negative twenty-four-faced trapezohedron*.

Axes.—The *cubical axes* join the opposite four-faced solid angles $P_1\ P_2$, &c., P_6, and

the *octahedral* the opposite six-faced solid angles, and are equal to the axes of the six-faced octahedron, from which the form is derived.

Inclination of the Adjacent Faces.—If θ be the angle of inclination of two adjacent angles over the shorter edge $P\,b_{1}$,

$$\cos.\ \theta = \frac{1 - \frac{1}{m^2} + \frac{1}{n^2}}{1 + \frac{1}{m^2} + \frac{1}{n^2}}$$

ϕ the angle of inclination of two adjacent faces over the longer edge $P_1\,b_{11}$,

$$\cos.\ \phi = \frac{1 + \frac{1}{m^2} - \frac{1}{n^2}}{1 + \frac{1}{m^2} + \frac{1}{n^2}}$$

And if ψ be the angle of inclination of two adjacent faces over edge $O\,b$,

$$\cos.\ \psi = \frac{\frac{1}{m} + \frac{1}{n} + \frac{1}{mn}}{1 + \frac{1}{m^2} + \frac{1}{n^2}}$$

Limits of the Form of the Irregular Twenty-four-faced Trapezohedron.—As m and n approach in magnitude to unity, the *irregular twenty-four-faced trapezohedron* approximates to the *octahedron;* and when m and n both equal unity, it becomes the octahedron. In this case the planes constituting the *three-faced solid angle* all lie in the same plane, and the edges, such as $P\,b$ and $b\,P$, are in the same line.

As m and n both increase in magnitude, and finally become infinitely great, this form approximates to and becomes the *cube.* In this case, the four planes forming the *four-faced solid angles* at the extremity of the cubic axes lie in the same plane, and the edges $o\,b$ and $b\,o$ in the same line.

As m approaches to unity while n increases in magnitude, and becomes finally infinitely great, the form approaches that of the *rhombic dodecahedron;* in this case two planes, on each side one of the longer edges $P\,b$, approach to and finally become in one plane, while the shortest edge, $b\,P$, becomes shorter and shorter, and finally vanishes. When m equals unity, while n remains finite, the form becomes the *three-faced octahedron,* and the trapezoidal faces change from trapeziums to isosceles triangles. When m and n equal each other, are both finite and greater than unity, the *irregular twenty-four-faced trapezohedron* becomes the *regular twenty-four-faced trapezohedron,* and the irregular trapeziums regular ones.

When m remains finite, and is greater than unity, and n becomes infinite, the form becomes that of the *pentagonal dodecahedron,* and the planes on each side the longer edge $P\,b$ lie in the same place.

From what has been said of the limits of the above form, it appears that each of the holohedral forms of the cubical system, with the exception of the *four-faced cube* and *six-faced octahedron,* which have their own hemihedral forms with parallel faces, may be regarded as limiting forms of the hemihedral forms with parallel faces.

As yet, the two hemihedral forms with parallel faces have only been observed in nature combined with one another and those of the holohedral forms, with the exception of the *six-faced octahedron* and *four-faced cube,* but never with any of the hemihedral forms with inclined faces.

To describe a Net for the Irregular Twenty-four faced Trapezohedron.—Describe the same figure (Fig. 123) as directed page 313, Fig. 52, with the exception of the lines $G\,R$, $P_1\,R$, $R\,P_2$ and $O_1\,R_3$.

Take C N $= \frac{1 - \frac{1}{n}}{1 - \frac{1}{r}}$ C P_1 and P_2 R = C N. Join N R.

Also take P_1 K $= \frac{1 - \frac{1}{m}}{1 - \frac{1}{r}}$. $P_1 B_1$ and C L = P_1 K. Join K L, cutting N R in *b*.

Join P_1 *b*. Let M be the point where E O_1 produced cuts C B_1.
Join L M. Take L S in $P_2 B_5$ = L M.
Through S draw S T parallel $A_1 B_5$ meeting E M in T, and join T *b*.

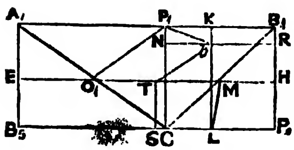


Fig. 123.

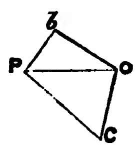


Fig. 124.

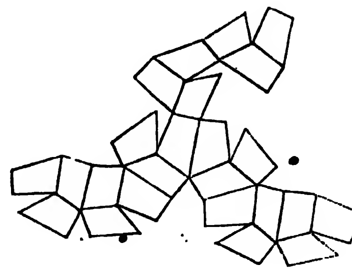


Fig. 125.

Then (Fig. 124) draw P O = P_1 O_1 (Fig. 123). On it describe a triangle P *b* O, having the side P *b* = P_1 *b* (Fig. 123), and *b* O = T *b* (Fig. 123).

On the other side of P O describe the triangle P C O having the side P C = *b* P_2 (Fig. 123), and O C = *b* T (Fig. 123).

P *b* O C will be the face of the *irregular twenty-four faced trapezohedron*, and twenty-four such faces, arranged as in Fig. 125, will form the required net.

Forms of the Irregular Twenty-four faced Trapezohedron which occur in Nature.—The form $\left[\frac{1, \frac{5}{4}, \frac{5}{3}}{2}\right]$, $\left[\frac{\frac{5}{3}\ O\ \frac{5}{4}}{2}\right]$ of Naumann, and π 5, 4, 3 of Miller has

$$\theta = 111^\circ\ 6' \qquad \phi = 129^\circ\ 48' \qquad \psi = 160^\circ\ 3'$$

Normals, whose faces are inclined at θ, ϕ, and ψ, 68° 54′; 50° 12′ and 19° 57′. Faces parallel to this form occur in crystals of Pyrite.

The form $\left[\frac{1, \frac{4}{3}, 2}{2}\right]$, $\left[\frac{2\ O\ \frac{4}{3}}{2}\right]$ of Naumann, and π 4, 3, 2 of Miller, has

$$\theta = 112^\circ\ 17' \qquad \phi = 136^\circ\ 24' \qquad \text{and } \psi = 153^\circ\ 43'.$$

Inclination of normals 67° 17′, 43° 36′, and 26° 17′.
Faces parallel to this form occur in Linneite.

The form $\left[\frac{1, \frac{15}{11}, \frac{15}{7}}{2}\right]$, $\left[\frac{\frac{15}{7}\ O\ \frac{15}{11}}{2}\right]$ of Naumann, and π. 4, 3, 2 of Miller, has

$$\theta = 112^\circ\ 47' \qquad \phi = 138^\circ\ 45' \qquad \text{and } \psi = 151^\circ\ 28'.$$

Inclination of normals 67° 13′, 41° 15′, and 28° 32′.
Faces parallel to this form occur in Linneite.

The form $\left[\frac{1, \frac{3}{2}, 3}{2}\right]$, $\left[\frac{3\ O\ \frac{3}{2}}{2}\right]$ of Naumann, and π 3, 2, 1 of Miller, has

$$\theta = 119^\circ\ 4' \qquad \phi = 149^\circ\ 00' \qquad \text{and } \psi = 141^\circ\ 47'$$

Inclination of normals 64° 37′, 31° 00′, and 38° 13′.
Faces parallel to this form occur in Cobaltine, Hauerite, and Pyrite.

The form $\left[\frac{1, \frac{5}{3}, 5}{2}\right]$, $\left[\frac{5\ 0\ \frac{5}{3}}{2}\right]$ of Naumann, and π, 5, 3, 1 of Miller, has

$$\theta = 119^\circ\ 4' \qquad \phi = 160^\circ\ 32' \qquad \text{and } \psi = 131^\circ\ 5'$$

Inclination of normals 60° 56′, 19° 28′, and 48° 55′.
Faces parallel to this form occur in Pyrite.

The form $\left[\frac{1, 2, 4}{2}\right]$, $\left[\frac{4\ 0\ 2}{2}\right]$ of Naumann, and π, 4, 2, 1 of Miller, has

$$\theta = 128^\circ\ 15' \qquad \phi = 154^\circ\ 47' \qquad \text{and } \psi\ 131^\circ\ 49'.$$

Inclination of normals 51° 45′, 25° 13′, and 48° 11′.
Faces parallel to this form occur in Pyrite.

Combination of the Cube and Tetrahedron. — When the faces of the *cube* P P, &c. (Fig. 126), predominate, the alternate solid angles of the cube are replaced by four triangular planes, O O, &c., which are parallel to those of the

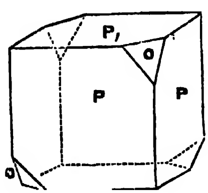


Fig. 126.

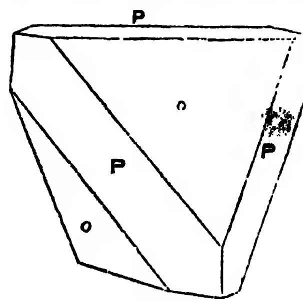


Fig. 127.

inscribed *tetrahedron*. When the faces O O, &c. (Fig. 127), of the *tetrahedron* predominate, each solid edge of the tetrahedron is replaced or truncated by a plane of the cube P_1 P, &c.

Combination of Cube and Twelve-faced Trapezohedron.—When the faces of the *cube* P P, &c. (Fig. 128), predominate, the alternate solid angles of the cube are replaced by an obtuse three-faced solid angle *b b b* of the trapezohedron, pre-

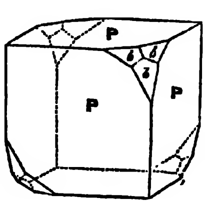


Fig. 128.

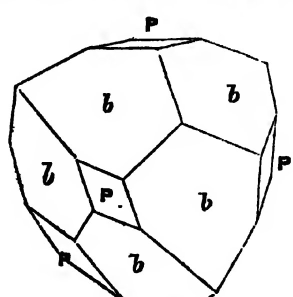


Fig. 129.

senting three trapeziums for each solid angle replaced. When the faces of the twelve-

faced *trapezohedron b b b* (Fig. 129) predominate, each four-faced solid angle of the trapezodedron is replaced by a rhomboidal plane of the cube P P, &c.

Combination of Cube and Three-faced Tetrahedron.—When the faces of the *cube* P P, &c. (Fig. 130), predominate, the alternate solid angles of the cube are

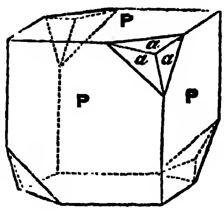


Fig. 130.

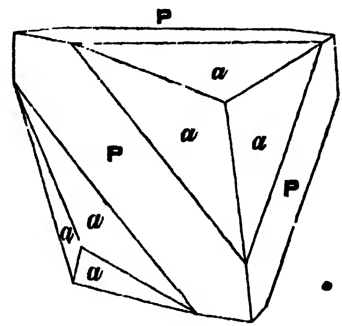


Fig. 131.

replaced by a three-faced solid angle of the three-faced tetrahedron, presenting three triangular planes *a a a* for each solid angle replaced.

When the faces of the *three-faced tetrahedron a a a* predominate (Fig. 131), the six longer edges of the three-faced tetrahedron are replaced by a plane of the cube P P P.

Combination of Cube and Six-faced Tetrahedron.—When the faces of the *cube* P P, &c. (Fig. 132), predominate, the alternate solid angles of the cube are each replaced by a six-faced solid angle *e e e*, &c., of the six-faced tetrahedron, consequently each alternate solid angle of the cube is replaced by six triangular planes.

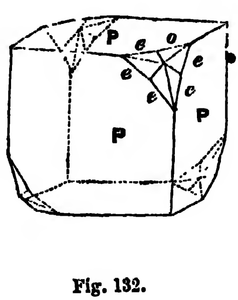


Fig. 132.

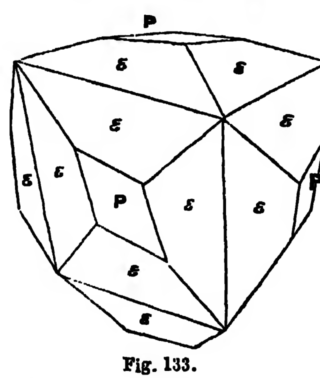


Fig. 133.

When the faces of the *six-faced tetrahedron* ε ε ε (Fig. 133) predominate, each four-faced solid angle of the the three-faced tetrahedron is replaced by a rhombic plane P P, &c., of the cube.

In the preceding combinations, it will be seen by comparing Figures 126, 128, 130, and 132 with 55, 60, 62, and 66, that *half* the solid angles of the cube are replaced by the same planes, when combined with the hemihedral forms with inclined faces; that *all* are when combined with their corresponding holohedral forms.

Combination of the Positive and Negative Tetrahedron.—In this com- combination (Fig. 134), the four three-faced solid angles of the positive *tetrahedron* *o o*, &c., whose faces predominate, are replaced by triangular planes *o' o'*, &c., of the negative tetrahedron. The four faces of the predominating tetrahedron *o o*, &c., are irregular hexagons. As the faces *o' o'*, &c., become larger, three edges of the hexahedron diminish; and when *o' o'*, &c., becomes so great that these edges disappear, the combination resolves itself into the regular *octahedron*.

This combination occurs in crystals of Blende (sulphuret of zinc), Boracite, Helvin, and Tennantite.

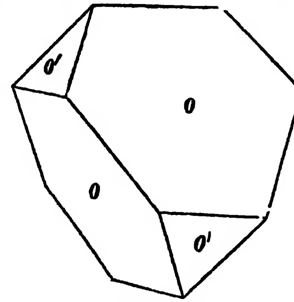


Fig. 134.

Combination of the Tetrahedron and Rhombic Dodecahedron.—In this combination (Fig. 135), the three-faced solid angles of the *tetrahedron* are each replaced by a three-faced solid angle of the *rhombic dodecahedron;* so that we have each solid angle of the tetrahedron replaced by three triangular faces *r r r*, of the rhombic dodecahedron, each triangular face being an isosceles triangle. When the faces of the *rhombic dodecahedron* predominate, half its three-faced solid angles are replaced by triangular planes of the tetrahedron, like those represented in Fig. 69.

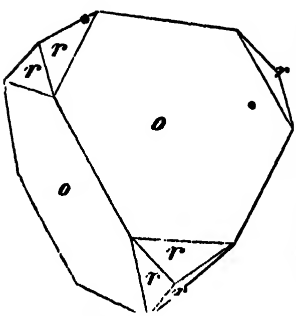


Fig. 135.

Combination of the Tetrahedron and Twelve-faced Trapezohedron.—When the faces of the *twelve-faced trapezohedron* *b b b*, &c. (Figs. 136 and 137), predominate, the obtuse three-faced solid angles of the *positive twelve-faced trapezohedron* are replaced by triangular planes *o o*, &c., of the *positive tetrahedron* (Fig. 136), and its

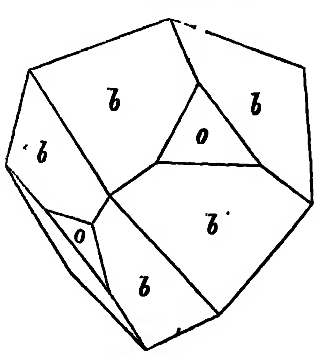


Fig. 136.

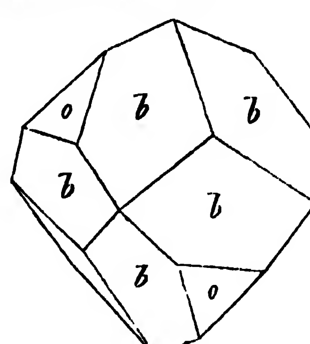


Fig. 137.

acute three-faced solid angles by triangular planes *o o*, &c. (Fig. 137), of the *negative tetrahedron.*

When the faces of the *positive tetrahedron o o*, &c. (Figs. 138 and 139), predominate, the three-faced solid angles of the *positive tetrahedron* are replaced by the acute three-faced solid angles *b b b*, &c., of the *positive twelve-faced trapezohedron* (Fig. 138), and by the obtuse three-faced solid angles *b b b*, &c., of the *negative twelve-faced trapezohedron* (Fig. 139.)

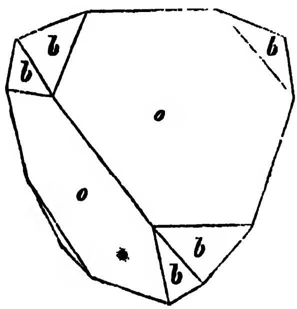


Fig. 138.

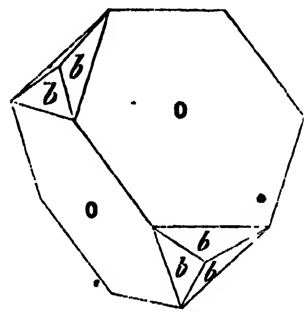


Fig. 139.

In Figs. 136 and 137, the faces of the tetrahedron *o o*, &c., are equilateral triangles; those of the trapezohedron *b b*, &c., irregular pentagons. In Figs. 138 and 139, the faces of the tetrahedron *o o*, &c., are irregular hexagons, and those of the trapezohedron *b b*, &c., isosceles triangles.

Combination of the Tetrahedron and Three-faced Tetrahedron.—When the faces of the *positive three-faced tetrahedron a a a*, &c. (Figs. 140 and 141), predominate, the three-faced solid angles of the *three-faced tetrahedron* are replaced by

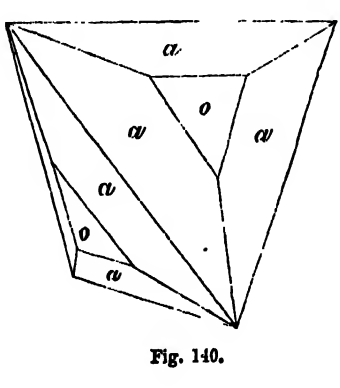


Fig. 140.

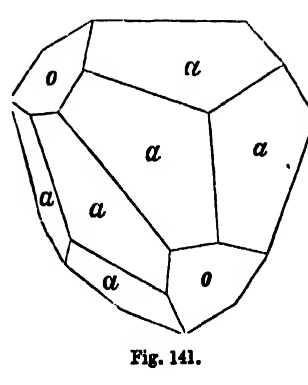


Fig. 141.

triangular planes *o o*, &c. (Fig. 140) of the *positive octahedron*, and its six-faced solid angles by irregular pentagonal planes of the *negative tetrahedron o o*, &c. (Fig. 141.)

When the faces of the *positive octahedron o o*, &c. (Figs. 142 and 143), predominate, its solid edges are each replaced by two planes of the *positive three-faced tetrahedron*, as *a a*, &c. (Fig. 142), and its three-faced solid angles by three trapezoidal

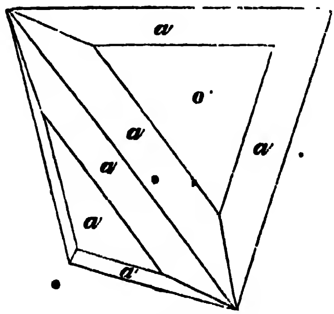


Fig. 142.

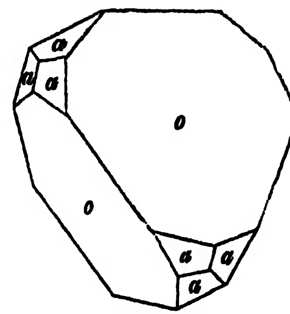


Fig. 143.

planes *a a*, &c. (Fig. 143), forming the three-faced solid angles of the *negative three-faced tetrahedron.*

Combination of the Tetrahedron and Six-faced Tetrahedron.—When the faces of the *six-faced tetrahedron e e e*, &c. (Figs. 144 and 145), predominate, the obtuse six-faced solid angles of the *six-faced tetrahedron* are each replaced by an irre-

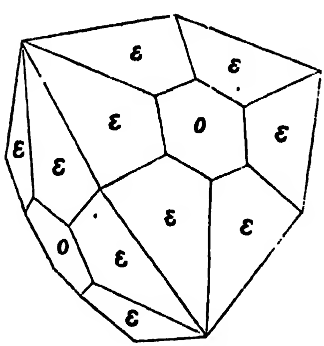


Fig. 144.

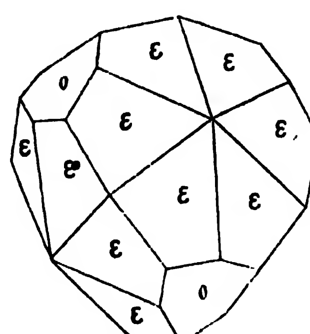


Fig. 145.

gular hexagonal plane *o o*, &c. (Fig. 144), of the *positive tetrahedron;* while its *acute* six-faced solid angles are each replaced by an irregular hexagonal plane *o o*, (Fig. 145), of the *negative tetrahedron*,

When the faces of the tetrahedron predominate, each three-faced solid angle of the tetrahedron is replaced by six planes constituting the *acute* six-faced solid angle of the *positive six-faced tetrahedron*, or by six planes constituting the *obtuse* six-faced solid angle of the *negative six-faced tetrahedron.*

Combination of Rhombic Dodecahedron and Twelve-faced Trapezohedron.—When the faces of the *twelve-faced trapezohedron b b*, &c. (Fig. 146), predominate, the acute three-faced solid angles of the *three-faced trapezohedron* are each replaced by three planes of the *rhombic dodecahedron r r*, &c., which form one of its three-faced solid angles. When the faces of the *rhombic dodecahedron* predominate, the alternate three-faced solid angles of the rhombic dodecahedron are replaced by the obtuse three-faced solid angles of the *twelve-faced trapezohedron.*

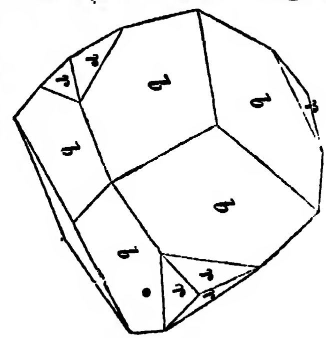


Fig. 146.

Combination of Rhombic Dodecahedron and Three-faced Tetrahedron.—Figures 147 and 148 show the combinations of the *rhombic dodecahedron* with

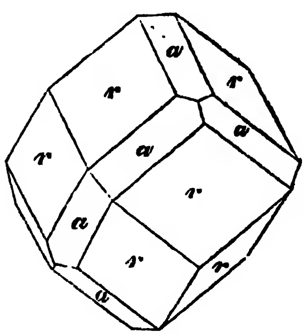


Fig. 147.

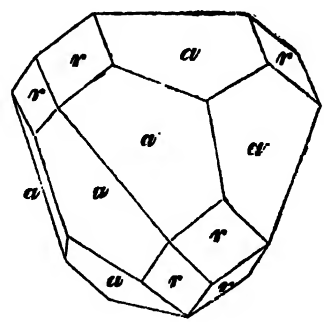


Fig. 148.

the *three-faced tetrahedron*, whose symbol is $-\frac{122}{2}$; and Fig. 149 its combination with

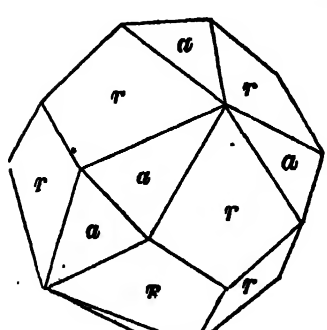


Fig. 149.

the *three-faced tetrahedron* whose symbol is $-\frac{133}{2}$. In Fig. 147, where the faces *r r*, &c., of the *rhombic dodecahedron* predominate, the edges of the four-three-faced solid angles of the rhombic dodecahedron, opposite the three-faced solid angles of the *three-faced tetrahedron* are replaced by planes *a a* of the latter. In Fig. 148 the six-faced solid angles of the *three-faced tetrahedron* are each replaced by a three-faced solid angle of the *rhombic dodecahedron*. In Fig. 149 each four-faced solid angle of the *rhombic dodecahedron* is replaced by two planes, *a ă*, of the *three-faced tetrahedron.*

Combination of Rhombic Dodecahedron with Six-faced Tetrahedron.—Figs. 150 and 151 represent the combinations of the *rhombic dodecahedron* with the *six-faced tetrahedron* whose symbol is $\frac{1\ \frac{3}{2}\ 3}{2}$, the faces marked *r* being those of the *rhombic dodecahehron*, and those marked *e* the faces of the *six-faced tetrahedron*. In Fig. 150 the three-faced solid angles of the *rhombic dodecahedron*, opposite to the

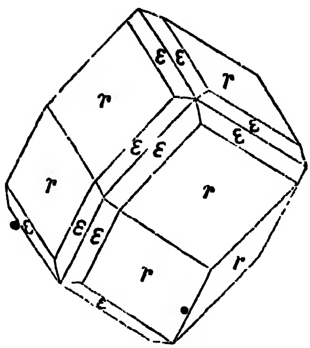


Fig. 150.

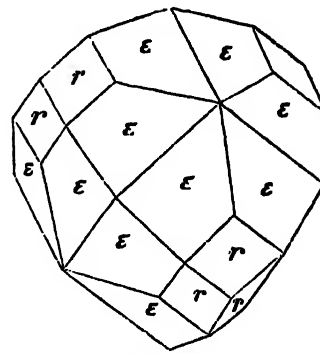


Fig. 151.

obtuse six-faced solid angles of the six-faced tetrahedron, have their edges replaced by two planes of the six-faced tetrahedron. In Fig. 151 where the faces of the *six-faced tetrahedron* predominate, the acute six-faced solid angles of that form are each replaced by a three-faced solid angle of the rhombic dodecahedron.

Combination of Cube with the Pentagonal Dodecahedron.—When the faces of the *cube* (P P, &c.,) predominate (Fig. 152), the edges of the cube are each replaced by a plane *c c*, &c., of the pentagonal dodecahedron. This combination is

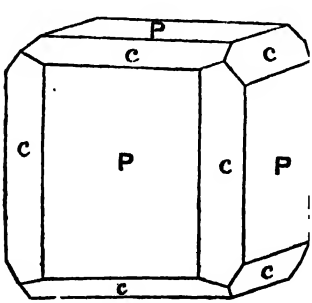


Fig. 152.

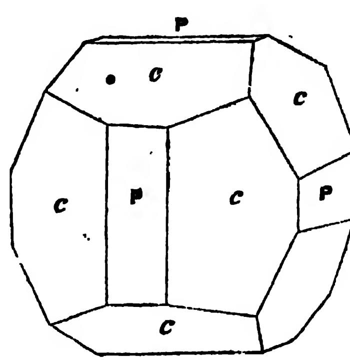


Fig. 153.

distinguished from that of the rhombic dodecahedron with the cube by the inclination of P on *c*, not being 135°. When the faces of the *pentagonal dodecahedron*, *c c*, predominate (Fig. 153), the edges of that form through which the cubical axes pass, are replaced by rectangular planes P P, &c., of the cube.

Combination of the Cube with the Hemihedral form of the Six-faced Octahedron with parallel faces.—When the faces of the *cube* P P, &c. (Fig. 154), predominate, the solid angles of the cube are each replaced by a three-faced solid angle,

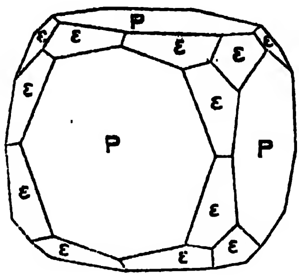


Fig. 154.

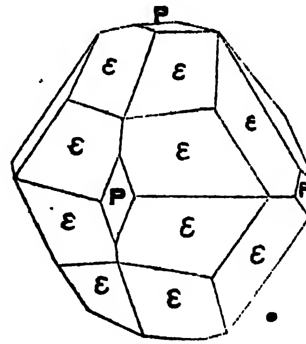


Fig. 155.

e e e, of the trapezohedron. When the faces *e e e*, &c., of the *trapezohedron* (Fig. 155) predominate, the four-faced solid angles of that form which terminate the cubical axes are each replaced by a plane P of the cube.

Combination of the Octahedron and Pentagonal Dodecahedron.—When the faces of the *octahedron o o*, &c. (Fig. 156) predominate, each four-faced solid angle of that form is replaced by two planes, *c c*, of the *pentagonal dodecahedron*. When the faces of the *pentagonal dodecahedron*, *c c*, &c. (Fig. 158), predominate, each of its three-faced solid angles which lie in the octahedral axes is replaced by a triangular plane, *o o*, of the octahedron. When the faces of the octahedron *o o*, &c. (Fig. 157), so

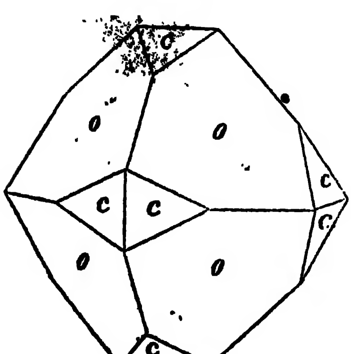


Fig. 156.

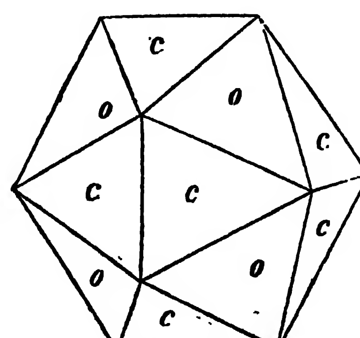


Fig. 157.

far prevail that their angular points touch each other, the combination presents the form shown in Fig. 157, bounded by eight equilateral triangles, *o o*, &c., and twelve isosceles triangles, *c c*, &c.

Platonic Bodies.—If the pentagonal dodecahedron be bounded by twelve regular pentagons,—that is, pentagons whose sides and angles are all equal,—it is called the *regular pentagonal dodecahedron.* In this case the isosceles triangles, *o o*, &c. (Fig 157), are equilateral triangles; and the combination of the regular pentagonal dodecahedron with the octahedron is a regular solid, bounded by twenty similar and equal equilateral triangles, and is called the *icosahedron.*

The tetrahedron, cube, octahedron, regular pentagonal dodecahedron, and the icosahedron, are the only *regular* solids which can be formed; a regular solid being one that is bounded by equal and similar regular rectilineal figures. These five solids are called the *platonic bodies.* The regular pentagonal dodecahedron and the icosahedron have not been observed among crystals.

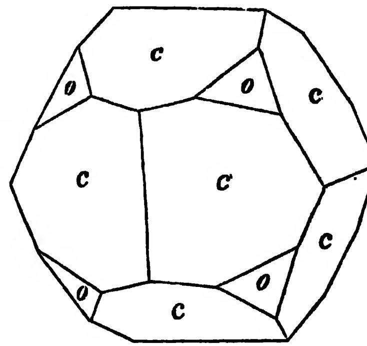


Fig. 158.

"The ancient geometricians made a great many geometrical speculations respecting these bodies; and they form almost the whole subject of the last books of Euclid's Elements. They were suggested to the ancients by their believing that these bodies were endowed with mysterious properties, on which the explanation of the most secret phenomena of nature depended."—*Ozanam's Mathematical Recreations.*

Combination of the Octahedron with the Hemihedral form of the Six-faced Octahedron with parallel faces.—When the faces *o o*, &c., of the *octahedron* (Fig. 159) predominate, its solid angles are each replaced by four planes, *e e e e*, of the

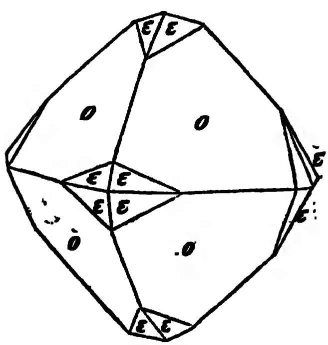


Fig. 159.

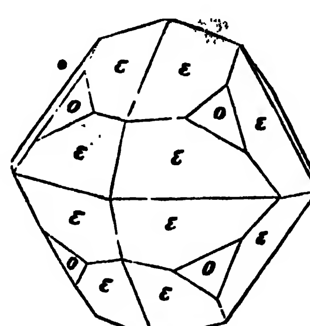


Fig. 160.

trapezohedron. When the faces of the *trapezohedron e e*, &c. (Fig. 160), predominate, each of its three-faced solid angles is replaced by a triangular plane, *o*, of the octahedron.

Combination of the Rhombic Dodecahedron with the Pentagonal Dodecahedron.—When the faces *r r*, &c., of the *rhombic dodecahedron* (Fig. 161)

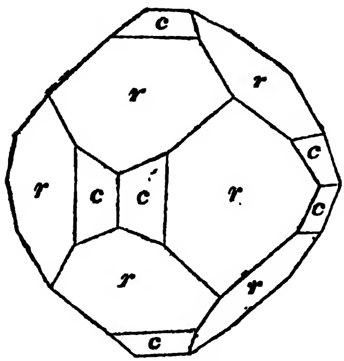


Fig. 161.

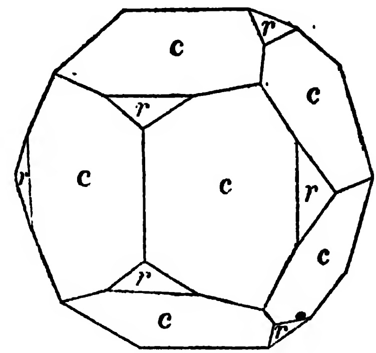


Fig. 162.

predominate, its four-faced solid angles are each replaced by two planes, *c c*, of the pentagonal dodecahedron. When the faces of the pentagonal dodecahedron, *c c*, &c. (Fig. 162), predominate, its four-faced solid angles are each replaced by a triangular plane, *r r*, &c., of the rhombic dodecahedron.

Combination of the Rhombic Dodecahedron with the Hemihedral form of the Six-faced Octahedron with parallel faces.—In this combination, the four-faced solid angles of the trapezohedron, *e e* (Fig. 163), are each replaced by a plane, *r r*, &c., of the rhombic dodecahedron.

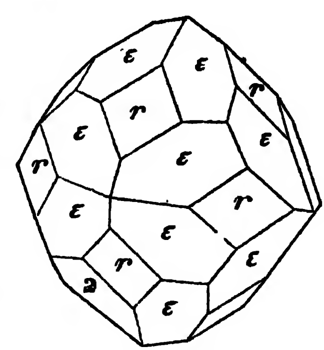


Fig. 163.

Complex Combination of Hemihedral Forms.—A crystal of Fahlerz, or grey copper ore, is represented in Fig. 164 as an instance of a complex combination of the hemihedral forms. The faces marked P are those of the *tetrahedron; f* those of the *cube; l* are the faces of the *positive three-faced tetrahedron;* and *r* those of the *negative three-faced tetrahedron*, which are both derived from the twenty-four-faced trapezohedron, whose symbol is 12 2. *o* are faces of the *rhombic dodecahedron*; *n* those of the *twelve-faced trapezohedron*, whose symbol is $\underline{1\ 1\ \tfrac{3}{2}}$. lastly, those marked *s* are the twenty-four faces of the seventh form which enters into this combination, and is the *four-faced cube* whose symbol is 1 3 ∞. This combination has seventy different faces.

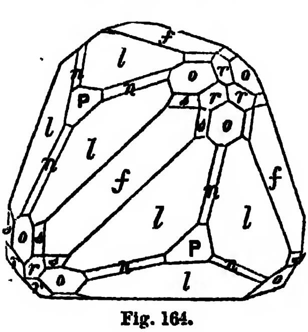


Fig. 164.

Molecules.—Under the head of cleavage, we have seen that crystals of many substances split in directions parallel to certain crystalline forms; thus Galena splits into rectangular fragments parallel to the sides of a *cube;* Fluor spar, into octahedral or tetrahedral particles parallel to the planes of the *regular octahedron;* and Blende (sulphuret of zinc), in particles parallel to the faces of a *rhombic dodecahedron.* To this cleavage there appears no limit but the practical difficulty of applying an instrument to the minute particles so as to split them. In the case of Calcite (carbonate of lime), which cleaves in obtuse rhomboids, it is found that the finest dust to which this substance can be reduced presents, under a powerful microscope, nothing but perfect though minute rhomboids. From these circumstances Haüy deduced the theory that the ultimate molecules, or particles of matter of Galena, were minute cubes; those of Fluor spar, regular tetrahedrons; of Blende, irregular tetrahedrons, having their faces parallel to three planes of the rhombic dodecahedron; and generally, that all crystals were composed of molecules whose forms might be determined from their cleavage, or inferred by analogy from their crystalline forms when the cleavage could not be discovered. These hypothetical solids Haüy calls the *primitive* solids of the substances from which they are deduced. Taking this *primitive* solid for his *primary* form, he deduces all the other crystalline forms in which the substance occurs from it, according to certain laws of *decrement*—that is, supposing his primary form to be composed of a large number of minute *primitive solids*, arranged together in a mass of the same form as themselves, he conceives the secondary forms to be derived from the primary one, by abstracting certain groups of these primitive solids, in regular order, from its solid angles and edges.

Law of Decrements.—Galena occurs in the forms both of the octahedron and rhombic dodecahedron as well as the cube. Haüy supposes these forms to be built up entirely of minute cubical particles, and formed from the cube by abstracting rows of cubical particles according to certain laws.

Decrements on Edges.—*Rhombic Dodecahedron.*—If a single row of cubical particles be removed from the edge of the large cubical mass, then two rows adjacent to the one removed, then three more rows adjacent to these, and so on, as in Fig. 165. If we conceive these cubical particles to be so small that the edges formed by their removal could not be perceived, the cubical mass would present the appearance of its edge being cut off by a plane, *a b c d*, Fig. 165, or r_1, Fig. 166. Let the process be

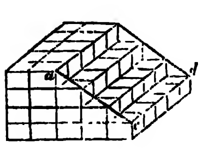


Fig. 165.

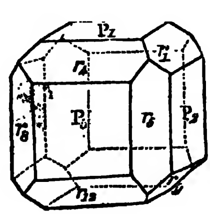


Fig. 166.

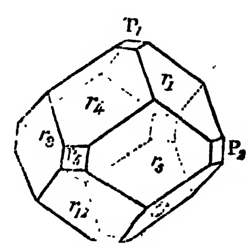


Fig. 167.

repeated on every edge of the cube, as in Fig. 166, and carried still further by the removal of more rows of cubical particles, as in Fig. 167, at length the form of the rhombic dodecahedron will appear.

Instead of producing the rhombic dodecahedron from the cube by decrements of the cubical molecules, we might suppose it built upon the cube by the addition of layers of these molecules; each successive layer being one row less, all the way round, than its preceding one, as shown in Fig. 168.

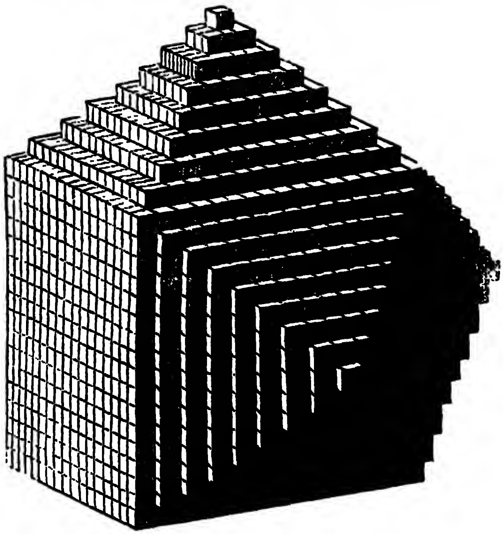


Fig. 168.

Marking the edges of the cube by the letters B, as in Fig. 18, the law of decrement for the formation of the rhombic dodecahedron is represented by the symbol B^1, the 1 above the B indicating the abstraction of single rows of cubical molecules parallel to the edges of the cube.

Four-faced Cube. — If we remove particles from the edge consisting of rows two in height and one in breadth, as in Fig. 169, the edge of the cube will be replaced by a plane, *a b c d*, corresponding to the plane c_1, Fig. 170. Considering P_2 as the upper

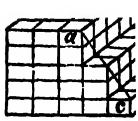


Fig. 169.

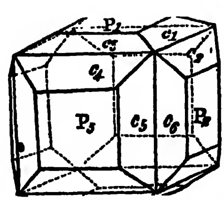


Fig. 170.

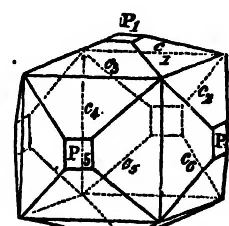


Fig. 171.

surface of the cube, similar rows of particles might be abstracted parallel to the edge between P_2 and P_1, producing the plane c_2. Repeating the process for every edge of the cube, we should have the form Fig. 170; and, abstracting equally more rows according to the above law, parallel to every edge, Fig. 65, we should ultimately form the four-faced cube.

The symbol for this decrement is $B^{\frac{1}{2}}$; the figure $\frac{1}{2}$ indicating that rows of molecules, one in breadth and two in height, are abstracted symmetrically in every possible manner from every edge of the cube.

$B^{\frac{m}{n}}$ would indicate a law of decrement by rows of particles m in breadth and n in height.

Fig. 172 represents the decrements which produce the *pentagonal dodecahedron*, which is the hemihedral form of the four-faced cube, whose symbol, according to Haüy's notation, is $B^{\frac{1}{2}}$. It is formed by decrements of rows along the edges of the cube two in height.

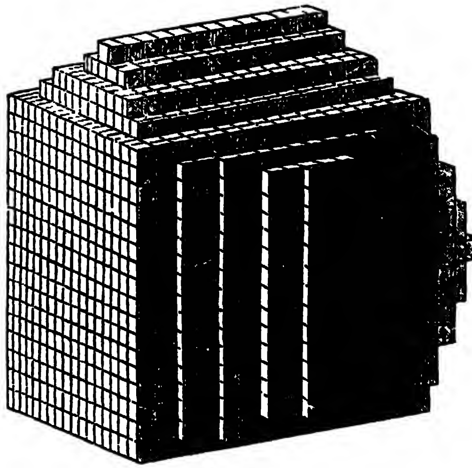


Fig. 172.

Decrements on the angles of the primary form.—If a single cubical molecule be removed from one of the solid angles of the cube, then the row of cubical molecules which touched the ones removed, then the next row which touched these, and so on, the solid angle of the cube would be replaced by a single plane, *a b c* (Fig. 173).

This law of decrement gives rise to the eight planes, o_1 o_2, &c., o_8, Figs. 55, 56, 57, producing the octahedron. The solid angles of the cube being indicated by the letter A, as in Fig. 14. The symbol for this decrement is A^1, the decrements from the solid angle being one in breadth and one in height.

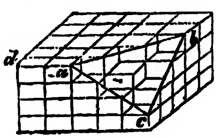


Fig. 173.

If the decrements from the solid angle consist of rows of groups of particles m in breadth and n in height, the symbol will be $A^{\frac{m}{n}}$.

When n is greater than m, or the height of each group greater than its breadth, a triangular plane *a b c* (Fig. 174), which is an isosceles triangle, having its sides greater than its base, replaces the solid angle of the cube and corresponds to the plane *b*

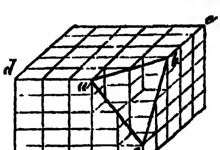


Fig. 174.

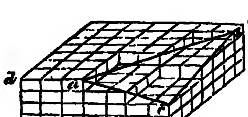


Fig. 175.

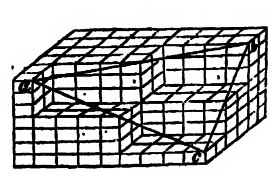


Fig. 176.

(Fig. 60). Since it is perfectly arbitrary on which face we suppose the cube to stand, by altering its position the same law would produce two similar planes b_2 and b_3, so that the solid angle would be replaced by the planes b_1 b_2 and b_3. Supposing every solid angle replaced by similar planes, this law of decrement gives rise (Figs. 60 and 61) to the *three-faced octahedron.*

When n is less than m, or the groups are less in height than breadth, the solid angle of the cube is replaced by an isosceles triangle *a b c* (Fig. 175), whose base is greater than its sides, corresponding to the plane a_1 (Fig. 62). This law of decrement replaces

every solid angle of the cube by three planes a_1 a_2 a_3 (Fig. 62), producing, as shown by Fig. 63, the *twenty-four faced trapezohedron.*

If the rows of particles removed from the solid angle consist of groups, such as those represented in Fig. 176, where each group is two cubical molecules in breadth, three in height, and four in length, the symbol for the decrement will be $B^{\frac{1}{2}}$, $B^{\frac{1}{3}}$, $B^{\frac{1}{4}}$, and the triangular plane replacing the solid angle will be a scalene triangle. According to the laws of symmetry, each solid angle of the cube may be replaced by six such triangles producing the planes e_1 e_2, &c., e_6 (Fig. 66). This law of decrement is that by which the *six-faced octahedron* (Figs. 66 and 67) is derived from the cube.

Mr. Brooke, whose modifications of Haüy's decrements we have given above, in his treatises on Crystallography, considers all substances whose crystals occur in any of the forms of the cubical system, as derived from the cube according to these laws, regarding the cube without reference to their cleavages as the primitive form of all.

By decrements of octahedral or tetrahedral particles from the edges and angles of the octrahedron, when the cleavage of a substance is octahedral and of irregular tetrahedrons from the edges and angles of the rhombic dodecahedron when the cleavage is parallel to it, Haüy derives all their other forms.

When a cube is supposed to consist of cubical molecules, the faces of these molecules

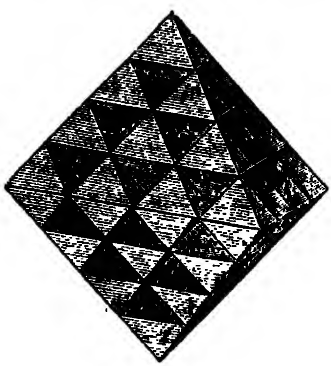


Fig. 177.

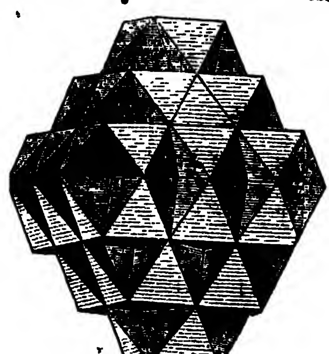


Fig. 178.

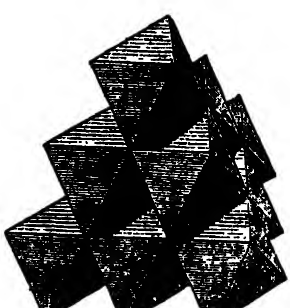


Fig. 179.

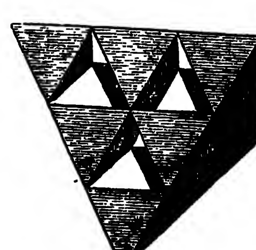


Fig. 180.

touch each other so as to leave no interstices, just as a solid wall is built up with bricks. If an octahedron be composed of octahedral molecules (Fig. 177), they can only touch

each other's edges, leaving tetrahedral spaces. Similarly a tetrahedron (Fig. 179) consisting of octahedral molecules must have tetrahedral spaces between them. An octahedron (Fig. 178) and tetrahedron (Fig. 180) composed of tetrahedral molecules will have octahedral spaces left between the molecules.

Spherical and Spheroidal Molecules.—Hooke and Wollaston contend that the ultimate molecules of substances crystallizing in forms of the cubical system are perfect spheres. Fig. 181 shows the arrangement of these spheres which produces the octahedron; Fig. 182, the tetrahedron; and Fig. 183, the cube. According to this

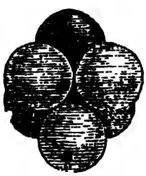


Fig. 181.

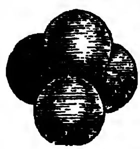


Fig. 182.

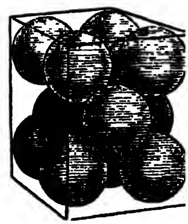


Fig. 183.

Fig. 184.

theory, the sphere may be substituted for the cube in every one of the cubical decrements we have described.

They derive the forms of the other systems of crystals from the combinations of prolate and oblate spheroids (Fig. 184).

Crystallographers generally have now abandoned these theories of the forms of the ultimate molecules of crystalline substances, on account of the numerous difficulties which a more extended view of the science has presented to their reception. They are now interesting as the means by which the relations of the faces of the crystalline forms to their axes were discovered, and we have given the outline of them, because they have had such a powerful influence on the nomenclature, and becomes so incorporated in the technical language of Chemistry and Mineralogy.

SECOND SYSTEM—THE PYRAMIDAL.

This system is called the *pyramidal* or *tetragonal* if its forms are derived from the *octahedron on a square base*, or *double four-faced pyramid*; the *square prismatic*, or *quadratic*, if derived from the *right prism on a square base*. It is also called the *monodimetrical*, or *two and one axial* system, from the properties of its axes.

The *holohedral forms* of this system are,—two *right prisms on a square base*, two *double four-faced pyramids*, the *double eight-faced pyramid*, and the *right prism on an octagonal base*.

From each of these, with the exception of the prisms on a square base, *hemihedral* forms are produced by the development of half their faces, and from one of the hemihedral forms of the *double eight-faced pyramid*, by the development of half its faces, a form is produced having only a fourth of the faces of the original form; this is called a *tetartohedral*, or *fourth-faced* form.

The hemihedral forms with inclined faces are the *sphenoid* or *tetrahedron*, the *eight-faced trapezohedron*, and the *scalenohedron*.

The hemihedral forms with parallel faces,—a *double four-faced pyramid*, and a *prism on a square base*.

The tetartohedral form is a *tetrahedron* or *sphenoid*.

Alphabetical List of the Minerals belonging to the Pyramidal System, together with the Angular Elements from which their Typical Form and Axes may be derived.

Anatase (Pyramidal Titanium)	60° 38′.
Apophyllite	51° 21′.
Autunite	51° 25′.
Braunite	54° 19′.
Calomel	60° 9′.
Cassiterite	33° 55′.
Chiolite	47° 8′.
Edingtonite	43° 39′.
Faujasite	52° 45′.
Fergusonite	55° 40′.
Gehlenite	Unknown.
Hausmannite (Pyramidal and Manganese Earth)	58° 57′.
Idocrase (Pyramidal Garnet)	28° 9′.
Lanthanite (Carbonate of Cerium)	Unknown.
Matlockite	60° 26′.
Mellite	36° 44′.
Naggagite (Black Tellurium)	61° 23′.
Phosgenite (Murio-carbonate of Lead)	47° 20′.
Rutile (Oxide of Titanium)	32° 47′.
Sarcolite	41° 35′.
Scapolite	23° 45′.
Scheelite	56° 1′.
Somervillite	32° 51′.
Stolzite (Tungstate of Lead)	57° 27′.
Tin	21° 5′.
Torberite	51° 25′.
Towanite (Pyramidal Copper Pyrites)	44° 34′.
Wulfenite (Molybdate of Lead)	57° 33′.
Zenotine (Phosphate of Yttria)	41° 0′.
Zircon	32° 38′.

The Square Prism.—The square prism, also called the tetragonal prism and the right prism on a square base, is a solid form bounded by six faces, four of which are rectangular parallelograms, such as $A_1 A_2 A_5 A_6$ (Fig. 185), forming the sides of the prism, and the other two—its top and bottom—are squares.

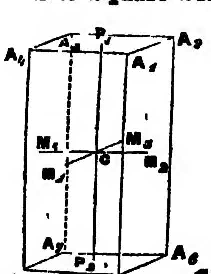


Fig. 185.

By some writers, the four faces alone which are parallelograms are considered the faces of the *square prism;* it is then called an open form, and the two square faces which are required to enclose it are considered distinct forms, under the name of *basal pinacoids.*

Axes of the Square Prism and the Pyramidal System.—Let P_1 and P_2 be the centres of the squares $A_1 A_2 A_3 A_4$, and $A_5 A_6 A_7 A_8$, which enclose the square prism; $M_1 M_2 M_3$ and M_4 the centres of the four rectangular faces. Join $P_1 P_2$, $M_1 M_3$, $M_2 M_4$ cutting each other in C.

The three lines, $M_1 M_3$, $M_2 M_4$, and $P_1 P_2$, which are at right angles to each other, are the *axes* of the *square prism*, and also of the *pyramidal system*.

Parameters.—The base of the square prism, and consequently the length of the equal axes $C M_1$ and $C M_2$, is perfectly arbitrary; the height of $C P_1$, or the height of the prism when a length has been chosen for $C M_1$ or $C M_2$, depends upon the angular element already given for each mineral belonging to this system. This angular element is determined from the angular measurement of some pyramid or octahedron whose faces occur most frequently among the crystals of any particular substance.

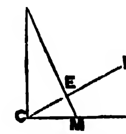


Fig. 186.

To determine $C P_1$, draw C M and C P (Fig. 186) at right angles to each other; take C M any convenient length, as the *arbitrary unit* of the system of axes.

Through C draw C D, making an angle with C P equal to the angular unit of the substance whose axes are to be represented.

Thus, for Anatase the angle P C D will be 60° 38′; for Apophyllite, 51° 21′; for Calomel, 60° 9′; and so on for other substances belonging to the pyramidal system.

From M let fall M E perpendicular to C D, and produce M E to meet the line C P in the point P.

The distances $C M_1$, $C M_2$, and $C P_1$, Fig. 185, of the points M_1 M_2 and P_1 from C thus determined, are called the *parameters* of the pyramidal system.

It appears, therefore, that the *axes* of the pyramidal system are *rectangular*, and two of its *parameters* are *equal*.

The edges of the *basal pinacoids*, or the breadth of the sides of the *square prism*, are twice the length of the equal parameters $C M_1$ or $C M_2$, and the height of the prism or its edge, such as $A_1 A_5$ (Fig. 185) is twice the length of C P.

To draw the square Prism.—Draw the line A_8 A_5 (Fig. 185) equal to twice C M (Fig. 186).

Through A_8 draw A_8 A_7, making an angle of about 30° with A_8 A_5.

Make A_8 A_7 equal half A_8 A_5. Through A_5 draw A_5 A_6 equal and parallel to $A_8 A_7$.

Through A_8 draw A_8 A_4 perpendicular to $A_8 A_5$, and equal twice C P (Fig. 186).

Through A_5 A_6 and A_7, draw A_5 A_1, A_6 A_2 and A_7 A_3 parallel and equal to A_4 A_8.

Join A_4 A_3, A_4 A_1, A_1 A_2, and A_3 A_2 and the square prism will be represented in perspective.

Symbols.—Each face of the *Square Prism* we have described, cuts one of the axes at a distance from the centre C of the axes, equal to the length of one of the equal parameters, and is parallel to the other two axes. The *two basal pinacoids* cut the axis at a distance equal to the *unequal parameter* and are parallel to the other two axes. Adopting, therefore, the same principle we have used in the cubical system, our symbol for this *square prism* will be 1 ∞ ∞, and for the *Basal Pinacoid* ∞ ∞ 1.

For this *square prism* Naumann's symbol is ∞ P ∞, Miller's 1 0 0, Brooke and Levy's modification of Haüy M, and Moh's [P + ∞].

For the *basal pinacoid* Naumann's is *o* P, Miller's 0 0 1, Brooke and Levy's P, and Mohs P — ∞.

To describe a net for the Square Prism.—Take the parallelogram $A_1\ A_4\ A_5\ A_8$ (Fig. 185) for one of the faces of the square prism, range four such parallelograms as in Fig. 187. Describe two squares having their sides equal to $A_1\ A_4$ (Fig. 185) and place them as in Fig. 187, and the net will be formed.

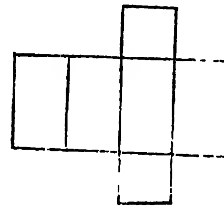


Fig. 187.

Minerals whose crystals present faces parallel to the square prism whose symbol is $1\ \infty\ \infty$:—

Apophyllite.
Cassiterite.
Calomel.
Edingtonite.
Gehlenite.
Idocrase.
Lanthanite.
Mellite.
Naggagite.
Phosgenite.
Rutile.
Sarcolite.
Scapholite.
Sommervillite.
Tin.
Torberite.
Towanite.
Wulfenite.
Zenotine.
Zircon.

Minerals whose crystals cleave parallel to this form,—those printed in italics indicating that the cleavage is easy and perfect :—

Cassiterite.
Calomel.
Edingtonite.
Gehlenite.
Phosgenite.
Rutile.
Scapolite.
Sommervillite.
Zenotine.

Minerals whose crystals present faces parallel to the basal pinucoids:—

Anatase.
Apophyllite.
Braunite.
Cassiterite.
Calomel.
Fergusonite.
Gehlenite.
Hausmannite.
Idocrase.
Lanthanite.
Matlockite.
Mellite.
Naggagite.
Phosgenite.
Rutile.
Sarcolite.
Scapolite.
Scheelite.
Sommervillite.
Stolzite.
Torberite.
Towanite.
Wulfenite.

Cleavages parallel to the basal pinacoids occur in the following minerals:—

Anatase.
Apophyllite.
Gehlenite.
Hausmannite.
Idocrase.
Lanthanite.
Naggagite.
Phosgenite.
Sommervillite.
Stolzite.
Torberite.
Towanite.
Wulfenite.

To draw the Second Square Prism.—Draw the axes $P_1\ P_2$, $M_1\ M_3$, and $M_2\ M_4$ as in Fig. 185. Through $M_1\ M_2\ M_3$ and M_4, draw $B_1\ B_5$, $B_2\ B_6$, $B_3\ B_7$, and $B_4\ B_8$

parallel and equal to $P_1 P_2$. Join $B_1 B_2$, $B_3 B_3$, &c., and a second square prism will be described in a different position from the former one.

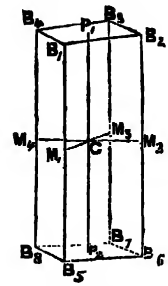


Fig. 188.

In this prism the axes in which the equal parameters lie, pass through its edges, while in the prism previously described they are perpendicular to its faces.

This prism, like the former, is an open form, closed by the same basal pinacoids perpendicular to the axis $P_1 P_2$.

Symbols.—Each face of this prism cuts two of the axes at a distance equal to that of the equal parameters from the centre C, and is parallel to the third. Thus the plane $B_1 B_2 B_5 B_6$ cuts the axes C M_1 and C M_2 in the points M_1 and M_2, and is parallel to C P_1. The symbol, therefore, which represents this relation of the faces of the prism to the axes is 1 1 ∞.

Naumann's symbol is ∞ P, Miller's 1 1 0, Brooke and Levy's ; Moh's P + ∞. This form being in all respects similar to that of the preceding square prism, except in the breadth of its faces, and its position with regard to the axes, its net will be described in the same manner as Fig. 187.

Faces parallel to the Square Prism whose Symbol is 1 1 ∞, *occur in the following minerals* :—

Anatase.	Phosgenite.	Stolzite.
Apohyllite.	Rutile.	Tin.
Cassiterite.	Sarcolite.	Torberite.
Calomel.	Scapolite.	Towanite.
Idocrase.	Scheelite.	Wulfenite.
Matlockite.	Somervillite.	Zircon.
Naggagite.		

The following Minerals have cleavages parallel to the Square Prism whose Symbol is 1 1 ∞ :—

Cassiterite.	Phosgenite.	Scapolite.
Idocrase.	Rutile.	Zircon.
Matlockite.		

Double Four-Faced Pyramid of the First Order.—The double four-faced pyramid, or octahedron on a square base, is a solid bounded by eight triangular faces, such as $P_1 G_1 G_4$, Fig. 189, each face being an isosceles triangle; it has four *four-faced solid angles*, $G_1 G_2 G_3 G_4$, formed by the equal angles of the isosceles triangles, and two *four-faced solid angles*, P_1 and P_2, formed by the unequal angles of the isosceles triangles. Four equal edges, $G_1 G_2$, &c.. which are the bases of the isosceles triangles, and eight other edges, $P_1 G_1$, $P_1 G_2$, &c., equal to one another, but unequal to the former, which are the sides of the isosceles triangles.]

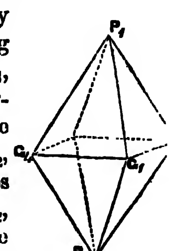


Fig. 189.

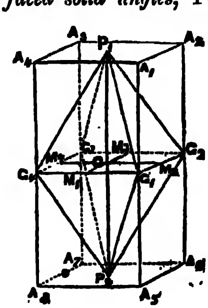


Fig. 190.

To Draw the Double Four-Faced Pyramid of the First Order.—Describe the square prism $A_1 A_2$, &c., A_8, with its axes $P_1 P_2$, &c., as directed for Fig, 185.

Through M_1, M_2, M_3 and M_4, Fig. 190, draw $G_4 G_1$, $G_1 G_2$, $G_2 G_3$, and $G_3 G_4$, parallel to $A_4 A_1$, $A_1 A_2$, $A_2 A_3$, and $A_3 A_4$, and cutting the edges of the prism in the points $G_1 G_2 G_3$ and G_4.

Join $P_1 G_1$, $P_1 G_2$, $P_1 G_3$, &c., as in Fig. 190, and the pyramid will be drawn.

Axes.—From the description of this pyramid it is evident that the axes in which the equal parameters are taken join the centres of the edges $G_1 G_2$, $G_2 G_3$, $G_3 G_4$, and $G_4 G_1$, which are the edges of the bases of two equal square pyramids which joined together form the figure, while the third axis joins the apices $P_1 P_2$ of the pyramids.

Symbols.—Each face of this double pyramid cuts one axis at a distance equal that of one of the equal parameters, the second axis at a distance equal to the unequal parameter, and is parallel to the third axis.

Thus the face $P_1 G_1 G_2$, Fig. 190, cuts the axis $C M_2$ in M_2, is parallel to the axis $C M_1$, and cuts the axis $C P_1$ in P_1.

The symbol which expresses this relation to the axes is $1 \infty 1$.

Naumann's symbol for this form is $P\infty$, Miller's 1 0 1, Brooke and Levy's b^1, and Moh's $P - 1$.

Inclination of the Faces.—Let ϕ be the inclination of the adjacent faces measured over the edges $G_1 G_2$, &c., θ their inclination over the edges $P_1 G_1$, &c., and α the angular element given, page 360.

$$\text{Then tan. } \frac{\pi - \phi}{2} = \text{cot. } \alpha \text{ and cos. } \pi - \theta = \left(\text{sin. } \frac{\pi - \phi}{2}\right)^2.$$

are the formulæ from which these inclinations may be determined.

To Describe a Net of the Double Four-Faced Pyramid whose Symbol is $1 \infty 1$.—Describe a square, $G_1 G_2 G_3 G_4$, Fig. 191, having its sides equal to twice $C M_2$, Fig. 190, or equal to twice the length of one of the equal parameters. This square will be the base of the double pyramid. Let C be its centre. Join $C G_1$, $C G_2$, $C G_3$, and $C G_4$. Then (Fig. 192), draw C P perpendicular to C G. Take $C P = C P_1$, Fig. 190, and $C G = C G_1$, Fig. 191. Join P G.

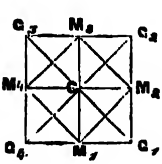


Fig. 191.

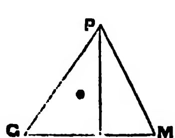


Fig. 192.

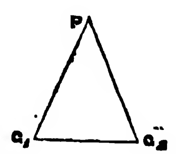


Fig. 193.

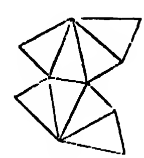


Fig. 194.

Draw $G_1 G_2$, Fig. 193, equal to $G_1 G_2$, Fig. 191.

On $G_1 G_2$ describe an isosceles triangle, $P_1 G_1 G_2$, having its equal sides, $P G_1$, $P G_2$, equal to P G (Fig. 192). $P G_1 G_2$ will be a face of the double four-faced pyramid, and eight such faces arranged, as in Fig. 194, will give the required net.

To Draw a Map of the projection of the Poles of the Double Four-Faced Pyramid whose Symbol is $1 \infty 1$, *upon the Sphere of Projection, as well as those of the Square Prisms already described.*—With P_1 as centre, and any convenient radius $P_1 M_1$, describe the circle $M_1 M_2 M_3$. Let $M_1 M_4$, and $M_2 M_3$, be any two diameters perpendicular to each other, $d_1 d_3$, and $d_2 d_4$, two diameters bisecting the right angles $M_1 P_1 M_2$, and $M_3 P_1 M_4$. Then P_1 will represent the north pole of the sphere of projection, and $M_1 M_2 M_3$ its equator.

P_1 will represent the pole of the basal pinacoid. M_1 M_2 M_3 M_4 the poles of the faces of the square prism whose symbol is $1\ \infty\ \infty$, d_1 d_2 d_3 and d_4 those of the faces of the square prism whose symbol is $1\ 1\ \infty$.

The poles a_1 a_2 a_3 a_4 of the double four-faced pyramid, whose symbol is $1\ \infty\ 1$, always lie where the circle of their latitude cuts the meridians C M_1, C M_2, C M_3, and C M_4; their latitude being equal to the angular element of the substance to which the crystal belongs.

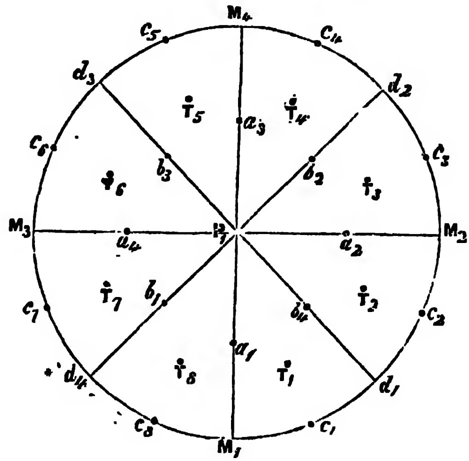


Fig. 195.

Crystals whose Faces occur parallel to the Double Four-Faced Pyramid, whose symbol is $1\ 1\ \infty$, *together with the latitude of their poles on the sphere of projection.*

Anatase	60° 38′
Braunite	54° 20′
Cassiterite	33° 55′
Calomel	60° 9′
Edingtonite	43° 39′
Fanjasite	52° 45′
Hausmannite	58° 57′
Idocrase	28° 9′
Matlockite	60° 26′
Mellite	36° 44′
Naggagite	61° 23′
Phosgenite	47° 20′
Rutile	32° 47′
Sarcolite	41° 35′
Scapolite	23° 45′
Scheelite	56° 1′
Somervillite	32° 51′
Stolzite	57° 27′
Tin	21° 5′
Torberite	51° 25′
Towanite	44° 34′
Wulfenite	57° 33′
Zenotine	41° 0′
Zircon	32° [illegible]

Three of these minerals cleave parallel to the form $1\ 1\ \infty$, Anatase, Braunite, and Cassiterite, the first two with a perfect cleavage.

Double Four-Faced Pyramid of the Second Order.—This pyramid differs from the former only in the position and size of its base. The same figure being described (Fig. 197) as Fig. 185.

Join $M_1 M_2$, $M_2 M_3$, $M_3 M_4$, and $M_4 M_1$; also join $P_1 M_1$, $P_1 M_2$, $P_1 M_3$, $P_1 M_4$, and $P_2 M_1$, $P_2 M_2$, $P_2 M_3$, $P_2 M_4$.

And the *double four-faced pyramid*, $P_1 M_1 M_2 P_2$, Figs. 196 and 197, of the second order, will be inscribed in the square prism.

In this prism, the axes in which the equal parameters lie, join the solid angles at the base of the pyramids $M_1 M_3$, and $M_2 M_4$.

In Fig. 191, let $M_1 M_2 M_3 M_4$ be the centres of the sides of the square.

Join $C M_1$ $C M_2$, &c., $C M_4$, and $M_1 M_2$, $M_2 M_3$, $M_3 M_4$, and $M_4 M_1$.

Then $M_1 M_2 M_3 M_4$ will represent the common base of the pyramids of the second order, $G_1 G_2 G_3 G_4$ that of the pyramids of the first order, and $M_1 M_2$, and $M_2 M_4$, the position of the axes with respect to these bases.

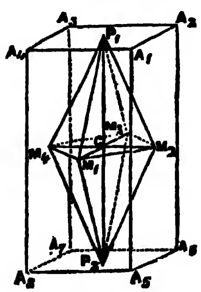


Fig. 196.

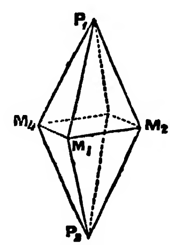


Fig. 197.

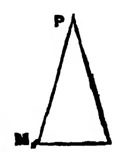


Fig. 198.

To find the face of this form, produce G C to M (Fig. 192). Make C M equal to $C M_1$, Fig. 191. Join P M.

Draw $M_1 M_2$, Fig. 198, equal to $M_1 M_2$, Fig. 191.

On it describe the isosceles triangle, $P M_1 M_2$, having the equal sides $P M_1$, $P M_2$, equal to P M, Fig. 192 $P M_1 M_2$ will be a face of the pyramid.

Eight such triangular faces, arranged as in Fig. 194, will form the net of the *double four-faced pyramid of the second order*

Symbols.—Every face of this form cuts the three axes at distances from its centre equal to that of the parameters; the symbol which expresses this relation is 1 1 1.

Naumann's symbol is P, Miller's 1 1 1, Brooke and Levy's a', Moh's P.

Inclination of Faces.—If ϕ be the angle of inclination of adjacent faces over the edges $M_1 M_2$, $M_2 M_3$, &c., θ that over the edges $P_1 M_1$, $P_2 M_2$, &c., and α that of the angular element, page 360.

$$\tan. \frac{\pi - \phi}{2} = \cot. \alpha \cos. 45^\circ.$$

$$\cos. (\pi - \theta) = \left(\sin. \frac{\pi - \phi}{2}\right)^2.$$

Position of the Poles of this Form on the Sphere of Projection.—The latitude of the poles of this form is the same for all, four lying in the same parallel of north latitude, and four in the same parallel of south latitude. Four poles lie in the zone passing through the pole P_1 of the form $\infty\ \infty\ 1$, and the poles d_1 and d_2 of the square prism,

whose symbol is 1 1 ∞. Thus b_1 b_2 b_3 b_4, Fig. 195, represent the poles of the double four-faced pyramid, whose symbol is 1 1 1.

Faces parallel to this form occur in the following minerals, the angles are the latitude of their poles :—

Anatase .	68° 18′
Apophyllite .	60° 32′
Calomel .	67° 55′
Cassiterite .	43° 33′
Chiolite .	56° 43′
Fergusonite .	64° 41′
Hausmannite	49° 36′
Idocrase .	37° 7′
Matlockite .	68° 9′
Mellite .	46° 33′
Naggagite .	68° 56′
Phosgenite .	56° 54′
Rutile .	42° 20′
Sarcolite .	51° 27′
Scapolite .	31° 54′
Scheelite .	64° 31′
Stolzite .	65° 42′
Tin . .	28° 36′
Towanite .	54° 20′
Wulfenite .	65° 47′
Zircon . .	42° 10′

Of these, Fergusonite, Hausmannite, Stolzite, Wulfenite, and Zircon, have *cleavages* parallel to this double four-faced pyramid.

Double Four-Faced Pyramids derived from the Form 1 ∞ 1.—Retaining the same base G_1 G_2 G_3 G_4, Fig. 190. Take C P_5 and C P_6, Fig. 199, equal to *m* times C P_1, Fig. 190, *m* being any fraction or whole number greater than unity. Join P_5 G_1, P_5 G_2, &c., as in Fig. 199, and the pyramid will be constructed.

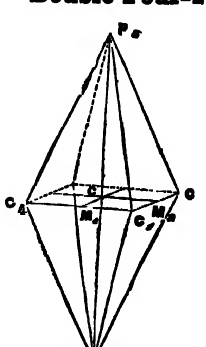


Fig. 199.

For Fig. 200 take C P_3, C P_4 = *m* C P_1 Fig. 190, *m* being a fraction less than unity.

Join P_3 G_1, P_3 G_2, &c., as in Fig. 200, and the pyramid will be constructed.

The series of pyramids, such as Fig. 199, are more acute, and those of Fig. 200 more obtuse, than the original pyramid 1 ∞ 1.

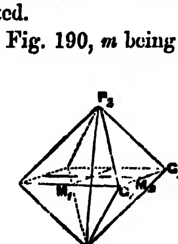


Fig. 200.

Symbols.—The symbol for these double four-faced pyramids is 1 ∞ *m*, as each face cuts one axis at a distance equal to one of the equal parameters, is parallel to the other, and cuts the third at a distance equal to *m* times the greater parameter.

Naumann's symbol is *m* P ∞, Miller's *h o l*, Brooke and Levy's, $b^{\frac{1}{m}}$.

Poles.—The poles of these pyramids always lie in the zone M P M, Fig. 195, those of the acute pyramids being between a and M, those of the obtuse between P and a: the poles of the upper pyramid lie in the same circle of north latitude, those of the lower in the same circle of south latitude.

Axes.—The axes C M_1, C M_2, &c., in which the equal parameters are taken, join the centres of sides of the base, Fig. 199 and 200, while the third joins the apices of the two pyramids.

Inclination of Faces.—If ϕ be the angle of inclination of adjacent faces over the edges $G_1 G_2$, $G_1 G_4$, &c., θ that over the edges $P_5 G_1$, $P_5 G_4$, &c., and a the angular element of the substance,

$$\text{Tan.} \frac{\pi - \phi}{2} = \frac{1}{m} \cot. a$$

$$\text{Cos.} (\pi - \theta) = \left(\sin. \frac{\pi - \phi}{2}\right)^2$$

Forms of the double four-faced pyramid whose symbol is 1 ∞ m *which have been observed in nature, together with the latitude of their poles on the sphere of projection.*

The form 1 ∞ $\frac{1}{5}$, $\frac{1}{5}$ P ∞ Naumann; 105 Miller; and b^5 Brooke and Levy.

Anatase	19° 31′.
Apophyllite	14° 3′.
Scheelite	16° 31′.

The form 1 ∞ $\frac{1}{3}$, $\frac{1}{3}$ P ∞ Naumann; 103 Miller; and b^3 Brooke and Levy.

Calomel	30° 9′.
Hausmannite	28° 58′.
Wulfenite	27° 40′.

Hausmannite cleaves parallel to this form.

The form 1 ∞ $\frac{1}{2}$, $\frac{1}{2}$ P ∞ Naumann; 102 Miller; b^2 Brooke and Levy.

Apophyllite	32° 2′.
Edingtonite	25° 26′.
Scheelite	36° 34′.
Torberite	32° 4′.
Wulfenite	38° 11′.

The form 1 ∞ $\frac{2}{3}$, $\frac{2}{3}$ P ∞ Naumann; 203 Miller; $b\frac{3}{2}$ Brooke and Levy.

Torberite	39° 53′.
Towanite	33° 18′.
Wulfenite	46° 21′.

The form 1 ∞ $\frac{3}{2}$, $\frac{3}{2}$ P ∞ Naumann; 302 Miller; $b\frac{2}{3}$ Brooke and Levy.

Towanite	55° 55′.
Wulfenite	67° 2′.

The form 1 ∞ 2, 2 P ∞ Naumann; 201 Miller; $b\frac{1}{2}$ Brooke and Levy.

Anatase	74° 14′.
Braunite	70° 15′.
Idocrase	46° 57′.
Torberite	68° 15′.
Towanite	63° 6′.

Torberite cleaves perfectly parallel to this form.

The form $1 \infty 3$, $3 P \infty$ Naumann; 301 Miller; $b^{\frac{1}{3}}$ Brooke and Levy.

Rutile	62° 38′.
Tin	49° 10′.

The form $1 \infty 5$, $5 P \infty$ Naumann; 501 Miller; $b^{\frac{1}{5}}$ Brooke and Levy.

Cassiterite	73° 26′.

When m becomes infinitely great this pyramid passes into the square prism whose sign is $1 \infty \infty$; as m approaches to zero the pyramid approximates to the basal pinacoid.

Double Four-faced Pyramids derived from the Pyramid of the Second Order.—Retaining the same base $M_1\,M_2\,M_3\,M_4$, as in Fig. 196 Take $C\,P_3$, $C\,P_6$, as in Fig. 201, equal to m times $C\,P_1$, Fig. 196, m being any fraction or whole number greater than unity.

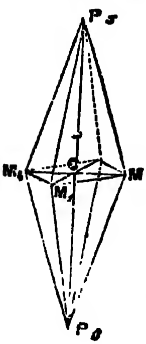


Fig. 201.

Join $P_3\,M_1$, $P_3\,M_2$, &c., as in Fig. 201.

For Fig. 201 take $C\,P_5$, or $C\,P_4$ equal to m times $C\,P_1$ (Fig. 196), m being less than unity.

Join $P_5\,M_1$, $P_5\,M_2$, &c., as in Fig. 202, and the pyramid will be constructed.

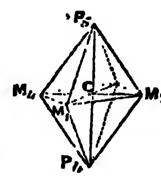


Fig. 202.

The series of pyramids, such as Fig. 201, are more acute, and those described as Fig. 202 are more obtuse than the original pyramid whose symbol is 1 1 1.

Symbols.—The symbol for these pyramids whose faces cut two of the axes at a distance equal to that of the equal parameters from their centre, and the third at a distance m times the greater paramentor, is 11 m. Naumann's symbol is mP, Miller's hhl, Brooke and Levy's $a^{\frac{1}{m}}$.

Poles.—The poles of these pyramids always lie in the zone $d\,P\,d$ (Fig. 195), those of the acute pyramids being between b and d, those of the acute being between P and b.

Axes.—The axes join the opposite four-faced solid angles.

Inclination of Faces.—If ϕ be the angle of inclination of adjacent faces over the edges $M_1\,M_2$, $M_2\,M_3$, &c. (Figs. 201 and 202), θ that over the edges $P_5\,M_1$, $P_5\,M_2$, &c., a the angular element of the substance,

tan. ·

$$\cos.(\pi - \theta) = \left(\sin. \frac{\pi - \phi}{2}\right)$$

Forms of the Double four-faced Pyramid, whose Symbol is 11 m, which have been observed in Nature, together with the Latitude of their Poles on the Sphere of Projection.

The form $1, 1, \frac{1}{16}$; $\frac{1}{16}\,P$ Naumann; 1, 1, 16 Miller; a^{16} Brooke and Levy.

Wulfenite	7° 55′.

The form $1, 1, \frac{1}{7}$; $\frac{1}{7}\,P$ Naumann; 1, 1, 7 Miller; a^{7} Brooke and Levy.

Anatase	19° 45′.

The form 1, 1, $\frac{1}{5}$; $\frac{1}{5}$ P Naumann; 1, 1, 5 Miller; a^5 Brooke and Levy.

Anatase	26° 14′.
Apophyllite	19° 30′.

The form 1, 1, $\frac{2}{9}$; $\frac{2}{9}$ P Naumann; 2, 2, 9 Miller; $a^{\frac{9}{2}}$ Brooke and Levy.

Wulfenite	26° 18′.

The form 1, 1, $\frac{1}{4}$; $\frac{1}{4}$ P Naumann; 1, 1, 4 Miller; a^4 Brooke and Levy.

Towanite	19° 23′.

The form 1, 1, $\frac{1}{3}$; $\frac{1}{3}$ P Naumann; 1, 1, 3 Miller; a^3 Brooke and Levy.

Anatase	30° 38′.
Idocrase	14° 10′.
Towanite	24° 55′.
Apophyllite	30° 32′.
Sarcolite	22° 41′.
Wulfenite	36° 33′.
Calomel	39° 24′.
Scheelite	34° 58′.

Wulfenite cleaves parallel to this pyramid.

The form 1, 1, $\frac{1}{2}$; $\frac{1}{2}$ P Naumann; 1, 1, 2 Miller; a^2 Brooke and Levy.

Idocrase	20° 44′.
Scheelite	46° 22′.
Stolzite	47° 55′.
Towanite	34° 52′.

The form 1, 1, $\frac{3}{5}$; $\frac{3}{5}$ P Naumann; 3, 3, 5 Miller; $a^{\frac{5}{3}}$ Brooke and Levy.

Cassiterite	29° 43′.

The form 1, 1, $\frac{3}{2}$; $\frac{3}{2}$ P Naumann; 3, 3, 2 Miller; $a^{\frac{2}{3}}$ Brooke and Levy.

Towanite	64° 26′.
Wulfenite	73° 19′.

The form 1, 1, 2; 2 P Naumann; 2, 2, 1 Miller; $a^{\frac{1}{2}}$ Brooke and Levy.

Idocrase	56° 33′.
Stolzite	77° 17′.
Towanite	70° 16′.
Zircon	61° 6′.

The form 1, 1, $\frac{5}{2}$; $\frac{5}{2}$ P Naumann; 5, 5, 2 Miller; $a^{\frac{2}{5}}$ Brooke and Levy.

Cassiterite	67° 21′.

The form 1, 1, 3; 3 P Naumann; 3, 3, 1 Miller; $a^{\frac{1}{3}}$ Brooke and Levy.

Idocrase	66° 34′.
Scapolite	61° 50′.
Tin	58° 34′.
Zircon	69° 48′.

The form 1, 1, 4; 4 P Naumann; 4, 4, 1 Miller; $a^{\frac{1}{4}}$ Brooke and Levy.

Idocrase	71° 43′.

As m increases in magnitude, this pyramid approaches to the square prism whose symbol is 1 1 ∞; and when m becomes infinite coincides with it.

Sphenoid derived from the Pyramid of the First Order.—By developing half the faces of the double four-faced pyramid of the first order, a hemihedral form, with inclined faces is produced, which is called a *sphenoid*, or *irregular tetrahedron*. Thus (Fig. 203), the four-faces $P_1 G_1 G_4$, $P_1 G_2 G_3$, $P_2 G_1 G_2$, and $P_2 G_3 G_4$ of the pyramid $P_1 G_1 G_2 P_2$ (Fig. 189) being produced till they meet, form the sphenoid $Q_1 Q_2 Q_3 Q_4$ (Fig. 203). This sphenoid may be called the *positive sphenoid*. The other four faces being produced till they meet, form another sphenoid equal in all respects to the former, and differing only in position; this is called the *negative sphenoid*.

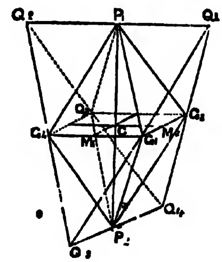


Fig. 203.

The *sphenoid*, so called from its wedge-like shape, is bounded by four isosceles triangles, such as $Q_1 Q_2 Q_3$; has six equal edges, such as $Q_1 Q_2$; and four three-faced solid angles Q_1, Q_2, Q_3 and Q_4.

To Draw the Sphenoid derived from the Pyramid of the First Order.—Through P_1 (Fig. 203) draw $Q_1 Q_2$ parallel to $G_1 G_4$; and through P_2, $Q_3 Q_4$ parallel to $G_1 G_2$. Make $P_1 Q_1$ and $P_1 Q_2$ equal to $G_1 G_4$, and $P_2 Q_4$ and $P_2 Q_3$ equal to $G_1 G_2$. Join $Q_1 Q_3$, $Q_1 Q_4$, $Q_2 Q_3$, and $Q_2 Q_4$. In a similar manner the sphenoids, derived from the double four-faced pyramids (Figs. 199 and 200), may be drawn.

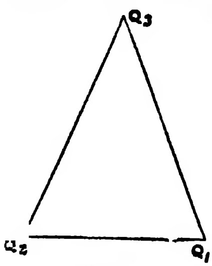


Fig. 204.

To Construct the Net for the Sphenoid.—Draw the line $Q_1 Q_2$ (Fig. 204) equal to twice $G_1 G_2$ (Fig. 193); on it describe the isosceles triangle $Q_1 Q_3 Q_2$, having each of its sides, $Q_1 Q_3$, $Q_2 Q_3$, equal twice $P G_1$ (Fig. 192). $Q_1 Q_2 Q_3$ will be a face of the sphenoid; and four such faces, arranged as in Fig. 205, will form the required net.

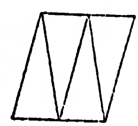


Fig. 205.

Crystals whose Faces occur parallel to the Sphenoid derived from the Pyramids of the First Order.

The sphenoid, derived from the pyramid whose symbol is 11∞, occurs in Edingtonite, Stobzite, Towanite and Wulfenite; and from the pyramid whose sign is $1\infty\frac{1}{2}$ in Edingtonite.

The poles a_1 a_3 of the *positive sphenoid* lie in the zone $M_1 P_1 M_4$ (Fig. 195), in the northern hemisphere of the sphere of projection; and the other two poles in the zone, $M_2 P_2 M_3$, in the southern hemisphere: a_2 a_4, poles of the *negative sphenoid*, lie in the zone $M_2 P_1 M_3$ of the northern hemisphere; the poles in the southern lie in the zone $M_1 P_1 M_2$.

Sphenoid derived from the Pyramid of the Second Order.—By developing, as in the last case, the alternate faces of the double four-faced pyramid (Fig. 197) whose symbol is 111, two hemihedral forms with inclined faces will be produced, which are sphenoids.

To Construct the Sphenoid.—Draw the prism $A_1 A_2 A_5 A_7$ (Fig. 206) as in Fig. 196. Join $A_1 A_3$, $A_6 A_8$, $A_1 A_8$, $A_1 A_6$, $A_3 A_8$, and $A_3 A_6$, and the *positive sphenoid* $A_1 A_3 A_8 A_6$

(Fig. 207) will be drawn. The *negative sphenoid* may be constructed by joining the points $A_2\,A_4$, $A_5\,A_7$, $A_2\,A_5$, $A_4\,A_5$, $A_2\,A_7$, and $A_4\,A_8$.

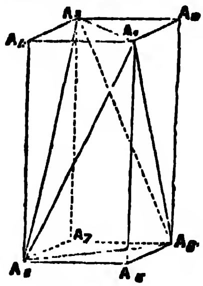


Fig. 206.

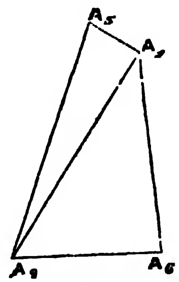


Fig. 207.

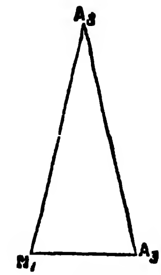


Fig. 208.

To Construct the Face of this Sphenoid.—Draw $A_1\,A_3$ (Fig. 208) equal to twice $M_1\,M_2$ (Fig. 198); on it describe the isosceles triangle $A_1\,A_8\,A_3$, having its sides $A_1\,A_8$, and $A_3\,A_8$, equal to twice $P\,M_1$ (Fig. 198). Four such triangles, arranged as in Fig. 205, will form the net for this sphenoid.

In a similar manner the sphenoids and their nets may be constructed, which are derived from the pyramids whose symbols are of the form 11 *m*.

Crystals whose Faces occur parallel to the Sphenoids derived from Pyramids of the Second Order.

The sphenoid derived from the pyramid whose symbol is 111 occurs in Stolzite, Towanite, and Wulfenite; and from the pyramids whose symbols are $11\frac{1}{2}$ and $11\frac{1}{3}$ in Towanite.

The poles $b_1\,b_2$ (Fig. 195) of the *positive sphenoid* lie in the zone $d_1\,P_1\,d_2$ of the northern hemisphere; and its other poles in the zone $d_3\,P_1\,d_1$ of the southern hemisphere of the sphere of projection. The poles $b_3\,b_4$ of the *negative sphenoid* lie in the zone $d_1\,P_1\,d_3$ of the northern, and its other poles in the zone $d_4\,P_1\,d_2$ of the southern hemisphere.

Octagonal Prism.—The *octagonal prism*, also called the *ditetragonal prism*, and the right prism on an octagonal base, is a solid bounded by ten faces, eight of which, such as $M_1\,E_1\,E_5\,M_5$, are rectangular parallelograms, forming the sides of the prism. The other two, forming the top and bottom of the prism, are irregular octagons. When this prism is considered an open form, its sides alone are considered the planes of the prism, and the two faces which inclose it are the planes of the *basal pinacoids*.

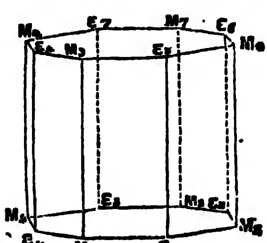


Fig. 209.

Axes.—The rectangular axes, in which the equal parameters are taken, join the points $M_1\,M_3$, and $M_2\,M_4$; while the third axis coincides with the geometrical axis of the prism.

Symbols.—Each face of the octagonal prism cuts one of the axes, as $C\,M_1$ (Fig. 190), at a distance $C\,M_1$ equal to the length of one of the equal parameters; the other axis, as $C\,M_2$, at a distance equal *n* times that parameter, where *n* may represent any whole

number or fraction greater than unity, and the face is parallel to the third axis C P_1, in which the unequal parameter is taken.

The symbol which expresses this relation to the axes is $1\ n\ \infty$.

Naumann's symbol for this form is ∞ P n, Miller's $h\ k\ o$, Brooke and Levy's g .

Inclination of the Faces.—Let ϕ be the angle of inclination of the faces measured over the edges $E_1\ E_5$, $E_2\ E_6$, &c., and θ over the edges $M_2\ M_6$, $M_3\ M_7$.

$$\text{Cos.}\ (\pi-\theta)=\frac{n^2-1}{n^2+1}\ \text{or tan.}\ \left(\frac{\pi-\theta}{2}\right)=\frac{1}{n},\ \text{and}\ \phi=270^\circ-\theta.$$

To Draw the Octagonal Prism.—Describe a square, $G_1\ G_2\ G_3\ G_4$ (Fig. 210) having each of its sides equal to twice the arbitrary unit chosen for the equal parameters of the system. Let C be the centre of the square, $M_1\ M_2\ M_3$ and M_4 the centres of its sides. Join $M_1\ M_3$ and $M_2\ M_4$, $G_2\ G_4$, and $G_1\ G_3$.

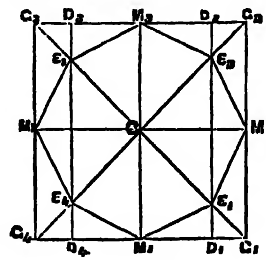


Fig. 210.

Let $M_1\ E_1$ be a line drawn from M_1 to meet C M_2, produced in a point at a distance equal to n times C M_2 from C; and let E_1 be the point where this line cuts C G_1. Take C E_2, C E_3, and C E_4, each equal to C E_1. Join $E_1\ M_2$, $M_2\ E_2$, $E_2\ M_3$, $M_3\ E_3$, &c. Through E_1 and E_4 draw $D_1\ D_2$, and $D_4\ D_3$, parallel to $G_1\ G_2$.

$M_1\ E_1\ M_2\ E_2$ &c. E_4, is the octagonal base of the prism whose symbol is $1\ n\ \infty$. To draw the prism, draw $G_1\ G_4$ (Fig. 214); make $G_1\ G_4$ equal $G_1\ G_4$ (Fig 210), and divide it similarly in the points $D_1\ M_1$ and D_4.

Through G_1 and G_4 draw $G_1\ G_2$, and $G_4\ G_3$ (Fig. 214), making an angle of about 30° with $G_1\ G_4$. Take $G_4\ M_4$, $G_3\ M_2$, $M_4\ G_3$, and $M_2\ G_1$, equal to half $G_4\ M_4$, $G_3\ M_2$, $M_4\ G_3$, and $M_2\ G_1$ of Fig. 210. Through D_4 and D_1 draw $D_4\ D_3$, and $D_1\ D_2$, parallel to $G_1\ G_2$.

Take $D_1\ E_1$, $D_1\ E_2$, $D_4\ E_4$, and $D_4\ E_3$, equal to half $D_1\ E_1$, $D_1\ E_2$, $D_4\ E_4$, and $D_4\ E_2$ (Fig. 209). Join $M_1\ E_1$, $E_1\ M_2$, &c. Then $M_1\ E_1$ &c. $M_4\ E_4$ (Figs. 214 and 209) will be a perspective representation of the octagonal base of the prism.

Through M_1 draw $M_1\ M_5$ (Fig. 209), perpendicular to $M_1\ E_1$, and of any height. Through E_1, M_2, E_3, M_3, &c., draw $E_1\ E_5$, $M_2\ M_6$, $E_2\ E_6$, $M_3\ M_7$, &c., parallel and equal to $M_1\ M_5$. Join $E_5\ M_6$, $M_6\ E_6$, &c., and Fig. 209 will be the representation of the octagonal prism in isometrical perspective.

Position of the poles of the Faces of the Octagonal Prism on the sphere of projection.—The poles of the faces of the octagonal prism always lie in the same zone, and that zone is the equator of the sphere of projection; $e_1\ e_2$, &c., e_8 (Fig. 195) represent these poles, each situated at the same angular distance from the points M_1, M_2, M_3, and M_4. The angle θ, given above, is this angular distance, and is the longitude of the pole reckoning from M_1.

Forms of the Octagonal Prism, parallel to which faces have been observed in nature, together with the longitude of their poles on the sphere of projection.

The form $1\ \frac{3}{2}\ \infty$, ∞ P $\frac{3}{2}$ Naumann; 230 Miller; and $g\frac{3}{2}$ Brooke and Levy, whose longitude is 33° 41′, occurs in crystals of Cassiterite, Fergusonite, Rutile, and Wulfenite.

The form $1\ 2\ \infty$, ∞ P 2 Naumann; 210 Miller; and g^2 Brooke and Levy, longitude

26° 34′, occurs in Apophyllite, Cassiterite, Idocrase, Phosgenite, Rutile, Scarcolite, and Sommervillite.

The form 1 3 ∞, ∞ P 3 Naumann; 310 Miller; and g^3 Brooke and Levy, longitude 18° 26′ occurs in Idocrase, Rutile, Scapolite, Towanite, and Wulfenite.

The form 1 4 ∞, ∞ P 4 Naumann; 410 Miller; and g^4 Brooke and Levy, longitude 14° 2′, occurs in Rutile.

The form 1 7 ∞, ∞ P 7 Naumann; 710 Miller; and g^7 Brooke and Levy, longitude 8° 8′, occurs in Rutile.

To describe a Net for the Octagonal Prism.—Draw two irregular octagons, equal to M_1 E_1 M_2 E_4 (Fig. 210), and eight rectangular parallelograms, each equal to M_1 E_1 E_5 M_5 (Fig. 209), and arrange these ten figures as in Fig. 211, and the net will be constructed.

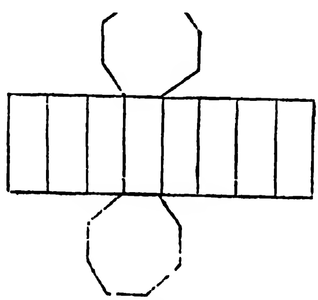


Fig. 211.

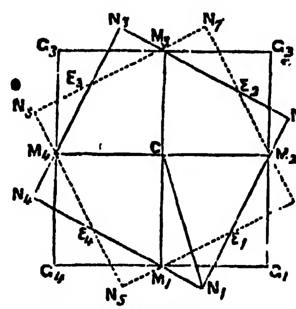


Fig. 212.

Hemihedral Form of the Octagonal Prism.—The same figure being constructed (Fig. 212) as in Fig 210. Produce M_1 E_1, M_2 E_2, M_3 E_3, and M_4 E_4 to meet in N_6, N_7, N_8, and N_5. Also produce E_4 M_1, E_1 M_2, E_2 M_3, and E_3 M_4 to meet in N_1, N_2, N_3, and N_4.

N_1 N_2 N_3 N_4 and N_6 N_7 N_8 N_5 will be two squares, which will be the bases of the square prisms which are the positive and negative hemihedral forms of the octagonal prisms with parallel faces.

This hemihedral form has been observed in crystals of Fergusonite and Wulfenite, derived from the octagonal prism whose symbol is 1 $\frac{4}{3}$ ∞.

Double Eight-faced Pyramid.—The double eight-faced pyramid, or pyramid on an octagonal base, called also the *ditetragonal* pyramid, is a solid bounded by sixteen faces, each face, such as P_1 E_1 M_1 (Fig. 213), being a scalene triangle. It has eight *four-faced solid angles* M_1, E_1, M_2, &c., corresponding to the angular points of the octagonal base of the pyramid; and two *eight-faced solid angles* P_1 and P_2, forming the apices of the pyramids.

It has eight equal edges, such as P_1 M_1, joining the eight-faced solid angles with the four-faced solid angles, through which the axes pass; eight other equal edges, such as P_1 E_1, joining the double eight-faced solid angles to the other four-faced solid angles; and eight more equal edges, such as M_1 E_1, joining the two kinds of four-faced solid angles.

Axes and Symbols.—The axes in which the equal parameters are taken join the four-faced solid angles M_1 M_3 and M_2 M_4 (Fig. 214), and the axis in which the unequal parameter is taken joins the points P_1 and P_2.

Every face of this pyramid cuts one of the axes, such as $M_1\,M_3$, at a distance equal to the arbitrary unit, the second $M_2\,M_4$ at a distance n times that unit, n being any whole number or fraction greater than unity, and the third axis $C\,P_1$ at a distance m times that of the unequal parameter, m being any whole number or fraction greater or less than unity.

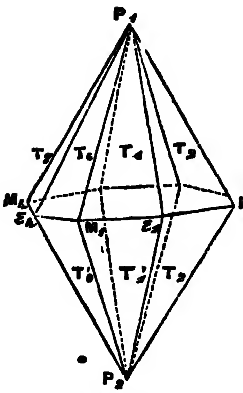


Fig. 213.

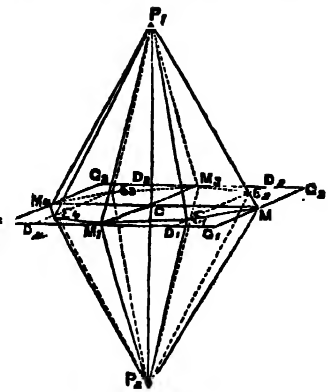


Fig. 214.

The symbol which expresses this relation of the figure to the axes of the pyramidal system, is $1\,m\,n$; Naumann's symbol is $m\,P\,n$; Miller's $h\,k\,l$; and Brooke and Levy's $b^{\frac{1}{h}}\;b^{\frac{1}{k}}\;g^{\frac{1}{l}}$.

To draw the Double Eight-faced Pyramid.—The same construction being made for the base of the pyramid (Fig. 210), as for the base of the octagonal prism whose symbol is $\infty\,P\,n$, this base is to be drawn in perspective (Fig. 214), in the manner in which the base of the octagonal prism was directed to be drawn. Through C draw $P_1\,C\,P_2$ perpendicular to $M_2\,M_4$, take $C\,P_1$ and $C\,P_2$ equal to m times the unequal parameter.

Join $P_1\,M_1$, $P_1\,E_1$, $P_1\,E_2$, $P_1\,M_2$, &c., $P_2\,M_1$, $P_2\,E_1$, &c., and the pyramid will be constructed.

To describe a Net for the Double Eight-faced Pyramid.—Draw C N (Fig. 215), equal to C N (Fig. 211), and C P perpendicular to C N. Make C P equal to m times the unequal parameter, the length of this parameter being determined by the method given in page 361, Fig. 186. Join P N.

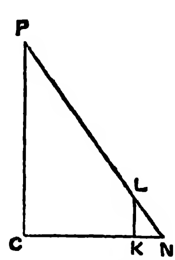


Fig. 215.

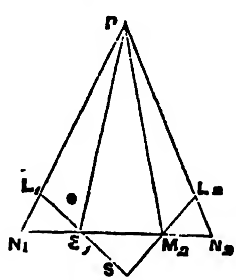


Fig. 216.

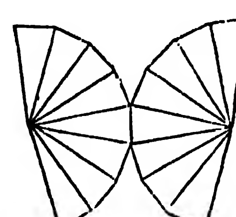


Fig. 217.

Then Fig. 216.—Draw $N_1\,N_2$ equal $N_1\,N_2$ (Fig. 212), and take in it the points E_1 and M_2, at the same distances from N_1 and N_2 they are in Fig. 212.

On $N_1\,N_2$ describe an isosceles triangle, $P\,N_1\,N_2$, having its sides, $P\,N_1$ and $P\,N_2$, equal to P N (Fig. 215). Join $P\,E_1$ and $P\,M_2$.

$P\,E_1\,M_2$ will be the scalene triangle which will be a face of the double eight-faced

pyramid, and sixteen such triangles, arranged as in Fig. 217, will form the required net.

Inclination of the Faces of the Double Eight-faced Pyramid.—Let a be the angular element for the substance among whose crystals faces of this pyramid occur, given in page 360. θ the inclination of adjacent faces, measured over the edges $P_1\,E_1$, $P_1\,E_2$, &c. (Figs. 212 and 213); ϕ over the edges $E_1\,M_1$, $E_1\,M_2$, &c.; and ψ over the edges $P_1\,M_1$, $P_1\,M_2$, &c.

Then if β be such an angle that cot. $\beta = n$,

$$\cot.\frac{\phi}{2} = \frac{1}{m}\cot. a \cos. \beta \qquad \cos.\frac{\theta}{2} = \sin.\frac{\phi}{2}\cos.(45^\circ + \beta) \qquad \cos.\frac{\psi}{2} = \sin.\theta \sin.\frac{\phi}{2}.$$

Position of the Poles of the Faces of the Double Eight-faced Pyramid on the sphere of projection.—The poles of the faces $T_1\,T_2$, &c., T_8 (Fig. 213), are represented on the map of the sphere of projection (Fig. 195), by $T_1\,T_2$, &c., T_8. All the poles of the upper faces of the pyramid occur in the same circle of latitude in the northern hemisphere of the sphere of projection, reckoning the latitude from P_1, and those of the lower faces of the pyramid in the same circle of south latitude, reckoning from P_2.

The angle $\frac{\phi}{2}$ in the preceding article will be the angle of latitude for the faces of the pyramid; and β will be the longitude of T_1, reckoning the longitude from $P_1\,M_1$ the first meridian of longitude.

The longitude of T_2 will be $90^\circ - \beta$, of T_3 $90^\circ + \beta$, of T_4 $180^\circ - \beta$, east of M_1, while the longitude of T_8, T_7, T_6, and T_5 will be the same angles west of M_1.

Crystals whose Faces occur parallel to the Double Eight-faced Pyramid, together with their Latitude and Longitude on the sphere of projection.

The form 1, 5, $\frac{5}{19}$; $\frac{5}{19}$ P 5 Naumann; 5, 1, 19 Miller; and $b^1\,b^{\frac{1}{5}}\,g^{\frac{1}{19}}$ Brooke and Levy.

Anatase, Lat. 25° 30′. Lon. 11° 18.

The form 1, 3, $\frac{1}{2}$; $\frac{1}{2}$ P 3 Naumann; 3, 1, 6 Miller; and $b^1\,b^{\frac{1}{3}}\,g^{\frac{1}{6}}$ Brooke and Levy.

Towanite, Lat. 27° 27′. Lon. 18° 26′.

The form 1, 2, 1; P 2 Naumann; 2, 1, 2 Miller; and $b^1\,b^{\frac{1}{2}}\,g^{\frac{1}{2}}$ Brooke and Levy.

Scheelite, Lat. 58° 55′. Lon. 26° 34′.

The form 1, 3, 1; P 3 Naumann; 3, 1, 3 Miller; and $b^1\,b^{\frac{1}{3}}\,g^{\frac{1}{3}}$ Brooke and Levy.

Cassiterite, Lat. 35° 20′. Lon. 18° 26′.
Rutile Lat. 34° 11′. Lon. 18° 26′.
Sarcolite, Lat. 43° 5′ Lon. 18° 26′.

The form 1, 3, $\frac{3}{2}$; $\frac{3}{2}$ P 3 Naumann; 3, 1, 2 Miller; $b^1\,b^{\frac{1}{3}}\,g^{\frac{1}{2}}$ Brooke and Levy.

Idocrase, Lat. 40° 41′. Lon. 18° 26′.

The form 1, 2, 2; 2 P 2 Naumann; 2, 1, 1 Miller; $b^1\,b^{\frac{1}{2}}\,g^1$ Brooke and Levy.

Idocrase, Lat. 50° 7′. Lon. 26° 34′.
Phosgenite, Lat. 67° 36′. Lon. 26° 34′.

The form 1, $\frac{3}{2}$, 3; 3 P $\frac{3}{2}$ Naumann; 3, 2, 1 Miller; $b^{\frac{1}{2}}\,b^{\frac{1}{4}}\,g^1$ Brooke and Levy.

Cassiterite, Lat. 67° 35′. Lon. 33° 41′.
Fergusonite, Lat. 79° 17′. Lon. 33° 41′.
Rutile, Lat. 66° 42′. Lon. 33° 41′.

The form 1, 3, 3; 3 P 3 Naumann; 3, 1, 1 Miller; b^1 $b^{\frac{1}{3}}$ g^1, Brooke and Levy.

Braunite,	Lat. 77° 13′.	Lon. 18° 26′.
Idocrase,	Lat. 59° 25′.	Lon. 18° 26′.
Sarcolite,	Lat. 70° 23′.	Lon. 18° 26′.
Scapolite,	Lat. 54° 18′.	Lon. 18° 26′.
Scheelite,	Lat. 77° 58′.	Lon. 18° 26′.
Zircon,	Lat. 63° 52′.	Lon. 18° 26′.

The form 1, 2, 4; 4 P 2 Naumann; 4, 2, 1 Miller; $b^{\frac{1}{2}}$ $b^{\frac{1}{4}}$ g^1 Brooke and Levy.

Idocrase,	Lat. 67° 20′.	Lon. 26° 34′.

The form 1, 4, 4; 4 P 4 Naumann; 4, 1, 1 Miller; b^1 $b^{\frac{1}{4}}$ g^1 Brooke and Levy.

Idocrase,	Lat. 65° 37′.	Lon. 14° 2′.
Zircon,	Lat. 69° 23′.	Lon. 14° 2′.

The form 1, 5, 5; 5 P 5 Naumann; 5, 1, 1 Miller; b^1 $b^{\frac{1}{5}}$ g^1 Brooke and Levy.

Idocrase,	Lat. 69° 53′.	Lon. 11° 18′.
Towanite,	Lat. 78° 44′.	Lon. 11° 18′.
Zircon,	Lat. 73° 0′.	Lon. 11° 18′.

Hemihedral Double Four-faced Pyramid.—If we represent the eight upper faces of the *double eight-faced pyramid* (Fig. 213) by the symbols T_1, T_2, T_3, T_4, T_5, T_6,

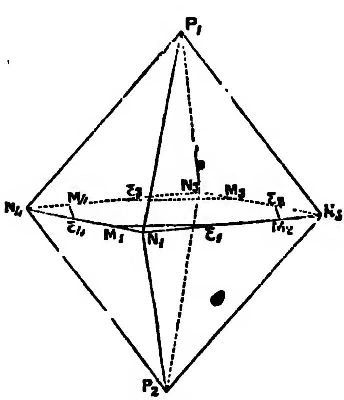


Fig. 218.

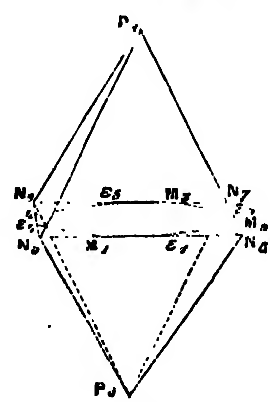


Fig. 219.

T_7 and T_8, and the corresponding lower faces by T'_1, T'_2, T'_3, T'_4, T'_5, T'_6, T'_7, and T'_8. Then if the eight faces T_1, T'_1, T_3, T'_3, T_5, T'_5, T_7, and T'_7, be produced till they meet, the resulting form will be the *double four-faced pyramid* P_1 N_5 N_6 P_2, &c. (Fig. 219). If the other eight faces of the *double eight-faced pyramid*, T_2, T'_2, T_4, T'_4, T_6, T'_6, T_8, and T'_8 be produced to meet, they will form the *double four-faced pyramid*. P_1 N_1 N_2 P_2, &c. (Fig. 218.)

These pyramids are equal to each other in every respect, and differ only in their situation with regard to the axes of the pyramidal system. They are the *positive and negative hemihedral forms with parallel faces* of the double eight-faced pyramid.

The axis in which the unequal parameters are taken join the apices P_1 and P_2 in both pyramids. The position in which the other two axes cut the bases of these pyra-

mids will be seen by referring to Fig. 212, where the lines $N_1 N_2$, $N_2 N_3$, $N_3 N_4$, and $N_4 N_1$, forming the square $N_1 N_2 N_3 N_4$, formed by producing the edges $E_1 M_2$, $E_2 M_3$, $E_3 M_4$, and $E_4 M_1$ of the base of the double eight-faced pyramid, is the base of the pyramid Fig. 218; and the square $N_5 N_6 N_7 N_8$ formed by the other edges of the base of the double eight-faced pyramid, is the base of the pyramid Fig. 219.

$M_1 M_3$ and $M_2 M_4$ will be the axes in both pyramids.

To draw the Hemihedral Double Four-faced Pyramids.—Draw the double eight-faced pyramid as described for the construction of Fig. 214. Produce $E_1 M_2$, $E_2 M_3$, $E_3 M_4$, and $E_4 M_1$ (Fig. 218), to meet in the points $N_1 N_2 N_3$ and N_4. Join $P_1 N_1$, $P_1 N_2$, &c., $P_2 N_1$, $P_2 N_2$, &c., and Fig. 218 will be constructed.

Produce $M_1 E_1$, $M_2 E_2$, $M_3 E_3$ and $M_4 E_4$ to meet in $N_5 N_6 N_7$ and N_8, and join these points with P_1 and P_2, and Fig. 219 will be constructed.

To Construct a Net for the Hemihedral Double Four-faced Pyramid.—The isosceles triangle $P N_1 N_2$ (Fig. 216) is a face of the double four-faced pyramid derived from the double eight-faced pyramid whose face is $P E_1 M_2$; and eight of these triangles, arranged as in Fig. 194, will form the required net.

Faces Parallel to the Hemihedral Double Four-faced Pyramid which occur in Nature.

In Scheelite from the pyramids 1, 2, 1, and 1, 2, 3. Sarcolite from the pyramid 1, 3, 1, and Fergusonite from the pyramid 1, $\frac{3}{2}$, 3.

Tetartohedral Form.—From each of the hemihedral double four-faced pyramids, two sphenoids may be derived by the development of half their faces, just as sphenoids are derived from the other double four-faced pyramids of the pyramidal system. These sphenoids would consequently be formed by the development of a fourth of the faces of the double eight-faced pyramids,, and are therefore called *tetartohedral forms* of that solid. It is doubtful whether any of these forms have been observed in nature.

Pyramidal Trapezohedron.—The *pyramidal trapezohedron*, also called the *tetragonal trapezohedron*, is a solid (Fig. 220), bounded by eight faces, each of which is an irregular trapezium, such as $P_1 L_1 S_1 L_2$ (Fig. 220), or $P L_1 S L_2$ (Fig. 216). It has two four-faced solid angles, P_1 and P_2, and eight more four-faced solid angles equal to one another $L_1 L_2 L_3 L_4$, and S_1, S_2, S_3, S_4. It has eight edges equal to $P L_1$ (Fig. 216) four equal to $L_1 S_1$, and four equal to $L_2 S_1$.

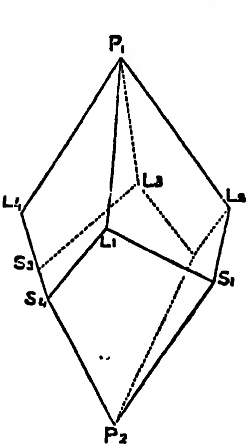


Fig. 220.

The pyramidal trapezohedron is a *hemihedral form, with inclined faces* of the double eight-faced pyramid, and is formed by producing the eight faces T_1, T'_2, T_3, T'_4, T_5, T'_6, T_7 and T'_8, to meet one another. A similar and equal trapezohedron would be formed by producing the faces T'_1, T_2, T'_3, T_4, T'_5, T_6, T'_7, and T_8 to meet.

This trapezohedron may also be regarded as formed by the combination of the upper half of a positive hemihedral four-faced pyramid, with the lower half of its corresponding negative hemihedral four-faced pyramid.

To Draw the Pyramidal Trapezohedron.—Draw the base of the double eight-faced pyramid $M_1 E_1$, $M_2 E_2$, &c. (Fig. 214), and its axis $P_1 P_2$ (Fig. 221). Produce $M_1 E_1$,

M_2 E_2, &c., to meet in N_5 N_6 N_7 and N_8, as in Fig. 212; and E_1 M_2, M_3, E_3, &c., to meet in N_1 N_2 N_3 N_4.

Join N_1, N_2, N_3 and N_4 with P_1 and N_5, N_6, N_7 and N_8 with P_2.

Then (Fig. 212) join C N_1, cutting M_1 E_1 in K.

In Fig. 215, take C K equal to C K (Fig. 212), and through K draw K L perpendicular to C N meeting P N in L.

In Fig. 221, take C H_1 and C H_2 in P_1 P_2, equal to K L (Fig. 215).

Through H_1 draw L_1 L_3 parallel to N_1 N_3, meeting P_1 N_1 and P_1 N_3 in L_1 and L_3, and L_2 L_4 parallel to N_2 N_4, meeting P_1 N_2, and P_1 N_4, in L_2 and L_4.

Through H_2 draw S_1 S_3 parallel to N_6 N_8, and S_2 S_4 parallel to N_7 N_5.

Join L_1 S_1 L_2, L_2 S_2 L_3, &c., as in Fig. 220, and the trapezohedron will be constructed.

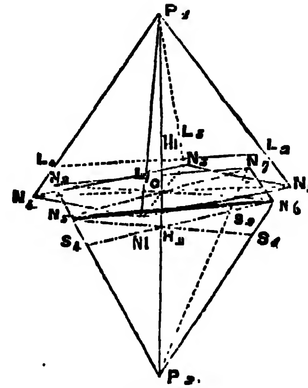


Fig. 221.

To Describe a Net for the Pyramidal Trapezohedron.—In Fig. 216, take P L_1 and and P L_2 in P N_1 and P N_2, equal to P L, Fig. 215.

Join L_1 E_1 and L_2 M_2, and produce these lines to meet in S.

P L_1 S L_2 will be a face of the trapezohedron; and eight such faces, arranged as in Fig. 222, will form the required net.

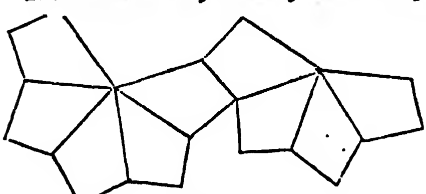


Fig. 222.

Faces parallel to the Pyramidal Trapezohedron which occur in Nature.—Faces parallel to the pyramidal trapezohedron have only been observed in crystals of Scapolite, derived from the double eight-faced pyramid whose symbol is 133.

Pyramidal Scalenohedron.—The *pyramidal scalenohedron*, also called the *tetragonal scalenohedron*, and by some the *diplo-tetrahedron*, is a solid bounded by eight faces, each of which, such as P_1 K_1 K_3 (Fig. 223), is a scalene triangle.

This is a *hemihedral form, with inclined faces*, of the double eight-faced pyramid, and is derived from it by producing the faces T_8, T_1, T'_2, T'_3, T_4, T_5, T'_6 and T'_7 (Fig. 213), to meet one another. Another scalenohedron, equal in all respects to this one, but differing in position, will be formed by producing T'_8, T'_1, T_2, T_3, T'_4, T'_5, T_6 and T_7. One of these may be called the positive and the other the negative scalenohedron.

This form has two four-faced solid angles P_1 and P_2, equal to each other; and four others, K_1 K_2 K_3 and K_4, equal to each other.

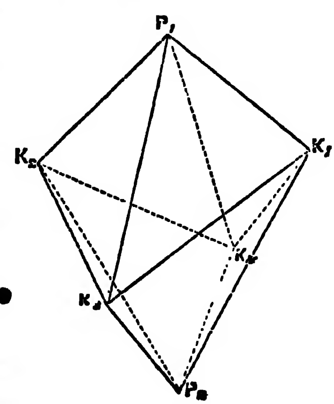


Fig. 223.

To draw the Pyramidal Scalenohedron.—Draw the base of the double eight-faced pyramid M_1 E_1 M_2, &c. (Fig. 224), as described for Fig. 214, as well as its axis P_1 P_2.

Produce $M_1 E_1$ and $M_3 E_2$ to meet in R_1, $M_1 E_4$ and $M_3 E_3$ to meet in R_2, also $M_2 E_1$ $M_4 E_4$ to meet in R_3, and $M_2 E_2$ and $M_4 E_3$ to meet in R_4.

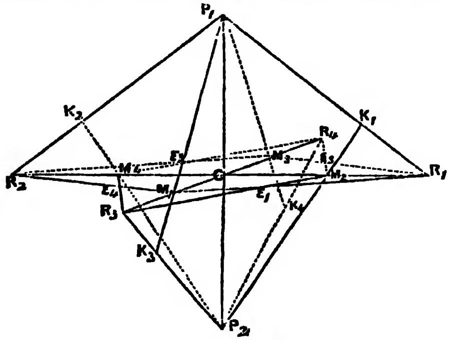


Fig. 224.

Join $P_1 M_1$ and produce it to meet $P_2 R_3$ in K_3, $P_2 M_2$ to meet $P_1 R_1$ in K_1, $P_1 M_3$ to meet $P_2 R_4$ in K_4, and $P_2 M_4$ to meet $P_1 R_2$ in K_2.

Join $K_1 K_4$, $K_4 K_2$, $K_2 K_3$, and $K_3 K_1$, as in Fig. 223, and the scalenohedron will be constructed.

To describe a Net for the Pyramidal Scalenohedron.—Draw a line $C P_1$ (Fig. 225), perpendicular to the line $C R_3$. Take $C P_1$ equal to $C P$ (Fig. 215), and $C M_1$ equal $C M_1$ (Fig. 212). Make $C R_2$ equal m, times $C M_1$; $1\ m\ n$ being the symbol of the double eight-faced pyramid, from which the scalenohedron is to be derived.

In $C P_1$ take $C M_2$ equal $C M_1$. Join $P M_1$ and $M_2 R_2$.

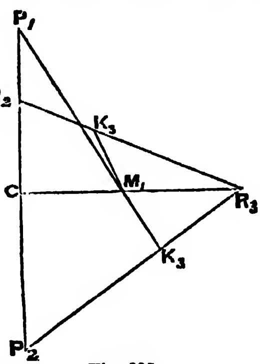


Fig. 225.

In $M_2 R_2$ take $M_2 K_3$ equal $M_2 E_1$ (Fig. 212). Join $M_1 K_3$.

Produce $P_1 C$ to P_2, and make $C P_2$ equal to $C P_1$. Join $P_2 R_2$, and produce $P_1 M_1$ to meet $P_2 R_3$ in K_2.

Then Fig. 226.—Draw the line $M_2 R_3$ equal to $M_2 R_2$ (Fig. 225), and on this as a base describe the triangle $M_2 P R_3$, having its side $M_2 P$ equal $M_1 P_1$ (Fig. 225), and its side $P R_3$ equal to $R_2 P_2$ (Fig. 225).

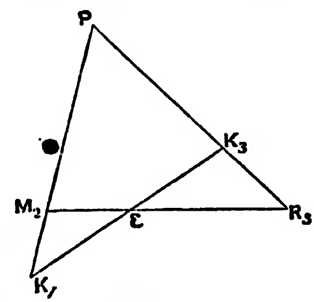


Fig. 226.

In $M_2 R_3$ take $M_2 E$ equal $M_2 K_3$ (Fig. 225), and in $R_3 P$, $R_3 K_3$ equal to $R_2 K_2$ (Fig. 225).

Join $K_3 E$, and produce it to meet $P M_1$ produced in K_1. $P K_1 K_3$ will be a face of the required scalenohedron; and eight such faces, arranged as in Fig. 227, will form the net for the scalenohedron.

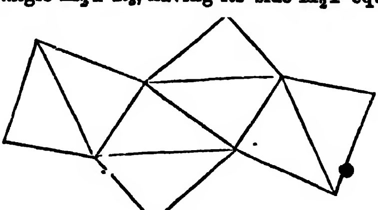


Fig. 227.

Faces parallel to the Pyramidal Scalenohedron which occur in Nature.

Faces parallel to this form have only been observed in crystals of Towanite or pyramidal copper pyrites, derived from the two double eight-faced pyramids whose symbols are 1, 3, $\frac{1}{3}$, and 1, 5, 5.

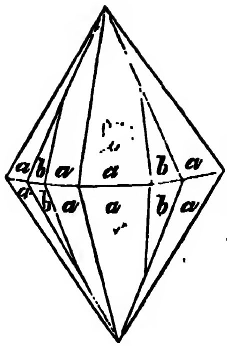


Fig. 228.

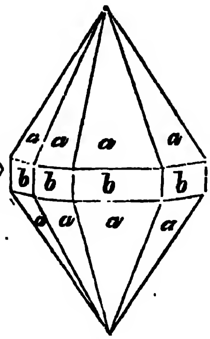


Fig. 229.

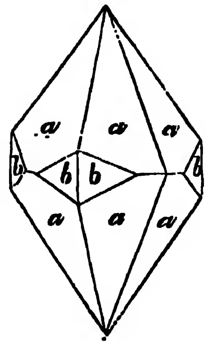


Fig. 230.

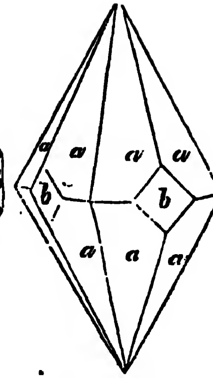


Fig. 231.

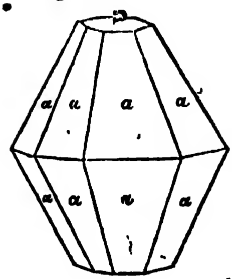


Fig. 232.

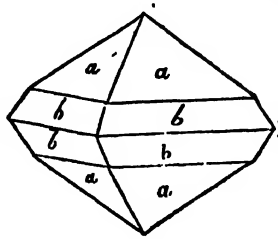


Fig. 233.

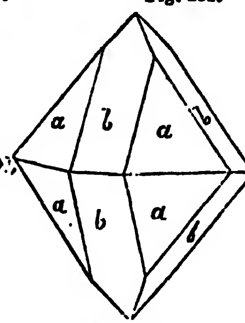


Fig. 234.

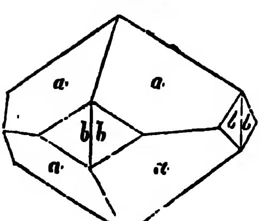


Fig. 235.

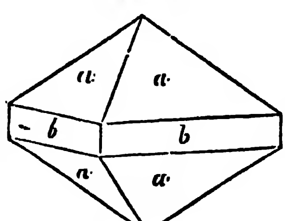


Fig. 236.

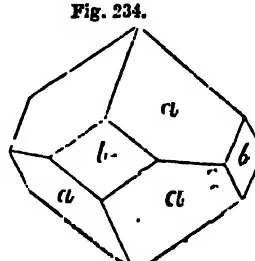


Fig. 237.

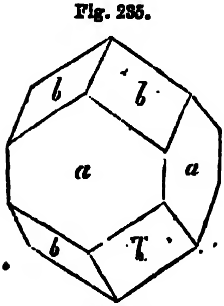


Fig. 238.

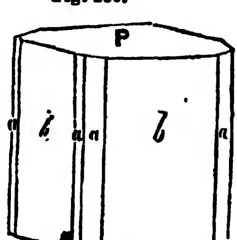


Fig. 239.

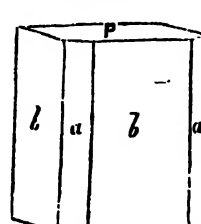


Fig. 240.

Principal combinations of the Pyramidal System.—A diligent study of the figures of these combinations, as already given, will enable us to read most, if not all, of the more complex combinations of this system. It is impossible, consistently with the limited space of an elementary work, to give all these combinations; but we hope those we have given will be quite sufficient for the purposes of the student.

Fig. 228. The *double eight-faced pyramid*, *a a a*, &c., whose symbol is 1 *n m*, with the alternate four-faced angles at its base replaced by faces *b b*, &c., of the *four-faced pyramid* whose symbol is 11 *m'*.

Fig. 229. The *double eight-faced pyramid*, *a a a*, &c., whose symbol is 1 *n m*, with the edges of its base replaced by faces *b b*, &c., of the *octagonal prism* whose symbol is 1, *n*, ∞.

Fig. 230. The *double eight-faced pyramid*, *a a a*, &c., whose symbol is 1 *n m*, with the alternate four-faced solid angles of its base replaced by two faces, *b b*, &c., of the *octagonal prism* whose symbol is 1, *n'*, ∞.

Fig. 231. The *double eight-faced pyramid*, *a a a*, &c., whose symbol is 1 *n m*, with the alternate four-faced solid angles of its base replaced by faces *b b*, &c., of the *square prism* whose symbol is 1 1 ∞.

Fig. 232. The *double eight-faced pyramid*, *a a a*, &c., with its eight-faced solid angles replaced by planes P P of the *basal pinacoid* whose symbol is ∞ ∞ 1.

Fig. 233. The *double four-faced pyramid*, *a a a*, &c., whose symbol is 111, with the edges at its base replaced by faces *b b*, &c., of the *double four-faced pyramid* whose symbol is 1 1 *m*.

Fig. 234. The *double four-faced pyramid*, *a a a*, &c., whose symbol is 1 1 1, with its edges replaced by faces *b b*, &c., of the *double four-faced pyramid* 1 ∞ 1.

Fig. 235. The *double four-faced pyramid*, *a a a*, &c., whose symbol is 1 1 1, with the four-faced angles at its base replaced by two planes of the *octagonal prism* 1 *n* ∞.

Fig. 236. The *double four-faced pyramid*, *a a a*, &c., whose symbol is 1 1 1, with the edges at its base replaced by faces *b b*, &c., of the *square prism* 1 1 ∞.

Fig. 237. The *double four-faced pyramid*, *a a a*, &c., whose symbol is 1 1 1, with the four-faced angles at its base replaced by faces *b b*, &c., of the square prism 1 ∞ ∞.

Fig. 238. The *square prism*, *a a a*, &c., whose symbol is 1 ∞ ∞, inclosed by faces *b b*, &c., of the *double four-faced* pyramid 1 1 1.

Fig. 239. The *square prism*, *b b b*, &c., whose symbol is 1 1 ∞, with its edges replaced by planes *a a*, &c., of the *octagonal prism* 1 *n* ∞, and inclosed by the planes P, P of the *basal pinacoid*.

Fig. 240. The *square prism*, *b b b*, &c., whose symbol is 1 1 ∞, with its edges replaced by planes *a a*, &c., of the *square prism* 1 ∞ ∞, and enclosed by planes P, P of the *basal pinacoid*.

Fig. 241. The *positive sphenoid*, *a a*, &c., derived from the double four-faced pyramid 1 1 1, with its three-faced solid angles replaced by planes *b b*, &c, of the *negative sphenoid* derived from the same pyramid.

Fig. 242. The *positive sphenoid*, *a a*, &c., with its three-faced solid angles replaced by faces *b b*, &c , of the *square prism* 1 1 ∞.

Fig. 243. The *positive sphenoid*, *a a*, &c., with four of its edges replaced by faces *b b*, &c., of the *square prism* 1 ∞ ∞.

Fig. 244. The *double four-faced pyramid*, *a a*, &c., whose symbol is 1 ∞ 1. with four of its edges replaced by faces *b b*, &c., of the *sphenoid* derived from the *double four-faced pyramid* 1 1 *m*.

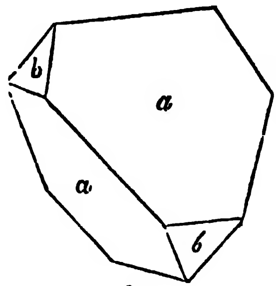


Fig. 241.

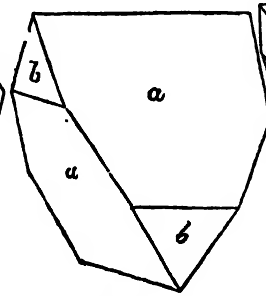


Fig. 242.

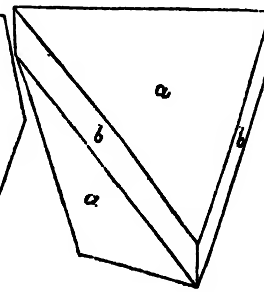


Fig. 243.

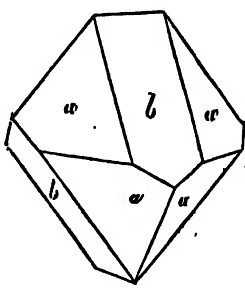


Fig. 244.

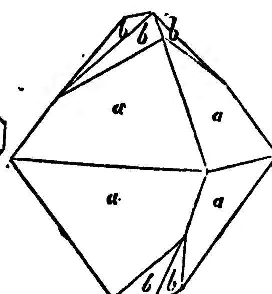


Fig. 245.

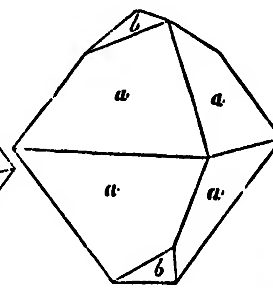


Fig. 246.

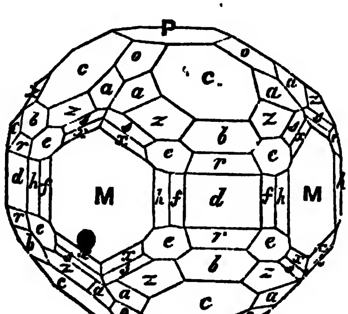


Fig. 247.

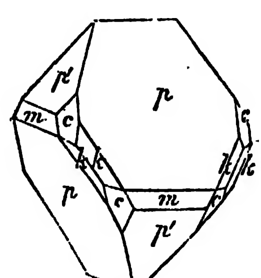


Fig. 248.

Fig. 245. The *double four-faced pyramid*, *a a*, &c., whose symbol is 1 ∞ 1, with the solid angles at its apices replaced by faces *b b*, &c., of the *scalenohedron*, derived from the *double eight-faced pyramid* 1 *n m*.

Fig. 246. The *double four-faced pyramid*, *a a*, &c., whose symbol is 1 ∞ 1, the solid angles at its apices replaced by faces *b b*, &c., of the *sphenoid* derived from the *double four-faced pyramid* 1 1 *m*.

Fig. 247. A complex holohedral combination of several forms of the pyramidal system in a crystal of Idocrase or pyramidal Garnet described by Mohs.

P, planes of the *basal pinacoid* ∞ ∞ 1.

Square prisms, M of the prism 1 ∞ ∞, *d* of the prism 1 1 ∞.

Octagonal prisms, *f* of the prism 1, 2, ∞ — *h* of the prism 1, 3, ∞.

Double four-faced pyramids, *o* of the pyramid 1 ∞ 1 — *c* of the pyramid 1, 1, 1 — *b* of the pyramid 1, 2, 1 — *r* of the pyramid 1, 4, 1.

Double eight-faced pyramids, *z* of the pyramid 1, 2, 2 — *s* of the pyramid 1, 3, 3 — *x* of the pyramid 1, 4, 4 — *e* of the pyramid 1, 2, 4 — *a* of the pyramid 1, 3, $\frac{3}{2}$.

Fig. 248. A complex hemihedral combination of forms of the pyramidal system in a crystal of Towanite or Pyramidal Copper Pyrites, described by Naumann, to whose works we take this opportunity of expressing our great obligation.

p, faces of the *positive sphenoid* derived from the four-faced pyramid 1 1 1.

p′, faces of the *negative sphenoid* derived from the same pyramid.

k, faces of the *scalenohedron* derived from the double eight-faced pyramid 1 5 5.

c, faces of the *four-faced pyramid* 1, ∞, 2, and *m* those of the *square prism* 1 1 ∞.

THIRD SYSTEM—RHOMBOHEDRAL.

This system is called the *rhombohedral* when its forms are derived from the *rhomboid*; the *hexagonal* when derived from the regular *hexagonal prism*, or the *double pyramid on a hexagonal base*. It has also been called the *monotrimetrical* and *three-and-one axial*, from the properties of its axes.

The *holohedral forms* of this system are, two kinds of *right prisms on a regular hexagonal base*; two orders of *double six-faced pyramids* on regular hexagonal bases; the double *twelve-faced pyramid*; and *the right prism on a twelve-sided base*.

From each of these, by producing half their faces to meet one another, *hemihedral forms* are derived.

The hemihedral forms, with *inclined faces*, are the *triangular prism*, derived from the hexagonal prism; the double *three-faced pyramid*, derived from the double six-faced pyramid; the *double six-faced trapezohedron*, derived from the double twelve-faced pyramid.

The hemihedral forms, with *parallel faces*, are the *hexagonal prism*, derived from the twelve-faced prism; the *double six-faced pyramid*, from the double twelve-faced pyramid; the *rhomboid*, from the *double six-faced pyramid*; and the *hexagonal scalenohedron*, derived from the double twelve-faced pyramid.

The *tetartohedral* forms are the *triangular* prism from the twelve-faced prism; the *rhomboid*, *double three-faced pyramid*, and *double three-faced trapezohedron*,—all derived from the double twelve-faced pyramid.

Some of these forms are either so rare or so doubtful, that we shall confine our descriptions to the different kinds of prisms, the double six-faced pyramids, the rhomboid, and the scalenohedron.

Alphabetical List of Minerals belonging to the Rhombohedral System, together with the Angular Elements from which their Typical Form and Axes may be derived.

Alunite (Alum Stone)	52° 45′.
Ankerite	43° 54′.
Antimony	56° 28′.
Apatite (Phosphate of Lime)	55° 40′.
Arsenic	57° 51′.
Biotite (Mica)	70° 00′.
Bismuth	56° 24′.
Breithauptite (Nickel Antimonial)	59° 47′.
Breunnerite	43° 8′.
Brucite	Unknown.
Calamine	42° 57′.
Calcite (Carbonate of Lime)	44° 37′.
Chabasie	50° 45′.
Chalybite (Carboniferous Oxide of Iron)	43° 23′.
Chlorite	66° 2′.
Clintonite	Unknown.
Cinnabar (Sulphuret of Mercury)	69° 17′.
Connellite (Sulphate Chloride of Copper)	Unknown.
Coquimbite	43° 50′.
Corundum	57° 34′.
Covelline	Unknown.
Cronstedtite	Unknown.
Davyne	59° 15′.
Diallogite (Carbonate of Manganese)	43° 29′.
Dioptase	50° 39′.
Dolomite (Bitter Spar)	43° 52′.
Emerald	44° 56′.
Eudialyte	67° 42′.
Fluocerite (Neutral Fluate of Cerium)	Unknown.
Gmelenite	Doubtful.
Graphite	Unknown.
Greenockite (Sulphuret of Cadmium)	58° 47.′
Hematite (Specular Iron)	57° 30′.
Hydrargillite	Unknown.
Ice	Unknown.
Ilmenite	57° 30′.
Kupfernickel (Copper Nickel)	58° 36′.
Levyne	43° 59′,
Magnesite (Carbonate of Magnesia)	43° 4′,
Mesitine	43° 14′.
Millerite (Native Nickel)	20° 50′.
Mimetite (Arseniate of Lead)	56° 19′.
Molybdenite (Sulphuret of Molybdena)	Unknown.
Nepheline	59° 10′.

Nitratine (Nitrate of Soda) . . .	43° 40′.
Osmiridium	58° 27′.
Parasite	81° 20′.
Phenakite	37° 19′.
Plattnerite	Unknown.
Polybasite	70° 31′.
Proustite (Red Silver)	42° 51′.
Pyrargyrite (Sulphuret of Silver and Antimony)	42° 18′.
Pyromorphite (Phosphate of Lead) . .	55° 49′.
Pyrosmalite	46° 42′.
Pyrrhotine (Magnetic Iron Pyrites) . .	60° 7′.
Quartz	51° 47′.
Ripidolite	66° 2′.
Riolite	Unknown.
Spartalite	37° 30′.
Stilpnomelane	Unknown.
Susannite	68° 38′.
Tamarite (Arseniate of Copper) . .	71° 16′.
Tellurium	57° 30′.
Tellurwismuth	Unknown.
Tetradymite	74° 44′.
Tourmaline	27° 20′.
Vanadinite (Vanadiate of Lead) . .	Unknown.
Willemite	30° 7′.
Xanthocone	69° 30′.

Hexagonal Prisms of the First and Second Order.—As in the pyramidal system, the two square prisms differ only in size and position, so in the rhomboidal

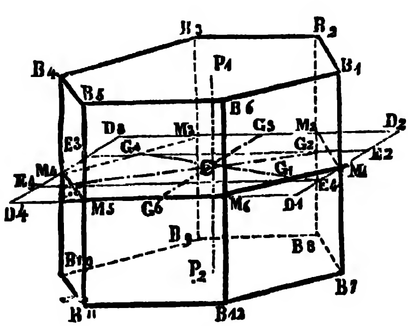


Fig. 249.

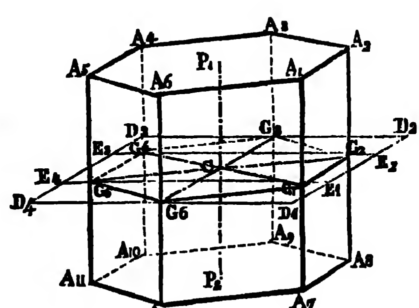


Fig. 25

system the hexagonal prisms differ from one another in the same manner. The hexagonal prism is a right prism standing on a base which is a regular hexagon; it is bounded therefore by eight faces, six of which—such as B_1 B_6 B_{12} B_7 (Fig. 249), and A_1 A_6 A_{12} A_7 (Fig. 250)—are rectangular parallelograms forming the sides of the

prism; the other two faces, forming the top and bottom of the prism, are regular hexagons.

By many writers the sides only of the hexagonal prism are considered as the faces of the *hexagonal prism;* the form being considered an *open* one. The two hexagonal faces which *inclose* it are then called *basal pinacoids.*

Axes of the Hexagonal Prism, and of the Rhomboidal System.—Let P_1 and P_2 be the centres of the hexagonal faces of the two hexagonal prisms (Figs. 249 and 250).

Join $P_1 P_2$. Bisect $P_1 P_2$ in C.

Let M_1, M_2, &c., M_6, be the centres of the edges $B_1 B_7$, $B_2 B_8$, &c., $B_6 B_{12}$, of the hexagonal prism of the first order (Fig. 249).

Join $M_1 M_2$, $M_2 M_3$, &c., $M_6 M_1$.

Bisect $M_6 M_1$, $M_1 M_2$, $M_2 M_3$, &c., by G_1, G_2, G_3, &c.

Join $G_1 G_4$, $G_2 G_5$, and $G_3 G_6$, cutting one another in C.

Let G_1, G_2, &c., G_6, be the centres of the edges of the hexagonal prism of the second order (Fig. 250).

Join $G_1 G_4$, $G_2 G_5$, and $G_3 G_6$, cutting one another in C.

Then in the case of both prisms, $P_1 P_2$, $G_1 G_4$, $G_2 G_5$, and $G_3 G_6$ will be the axes of the prisms, and of the *rhomboidal system.*

It follows, therefore, that in this system there are four axes, three of which lie in the same plane, and are inclined to each other at an angle of 60°; and the third passes through their intersection, and is perpendicular to their plane. C G_1 C G_2 C G_3, are the three equal parameters of this system, and a fourth unequal parameter is taken in the axis C P_1. The forms of the rhomboidal system are derived from these axes by most of the continental crystallographers; but Professor Miller refers them to three equal axes derived from a particular rhomboid for each substance, in the following manner.

Let $P_1 R_1 R_2$, &c., P_2, (Fig. 251), be a particular rhomboid (*i. e.*, a figure bounded by six equal rhombs), chosen, for each substance which crystallizes in this system, as its typical form. Join the opposite angles of every face. Let H_1 be the point where $P_1 R_1$ meets $R_2 R_6$; H_1 is the centre of the face $P_1 R_1 R_2 R_6$. Let H_2, H_3, H_4, H_5 and H_6, be the centres of the other faces of the rhomboid found in a similar manner.

Join $H_1 H_4$, $H_2 H_5$, and $H_3 H_6$, the centres of the opposite faces of the rhomboid, cutting each other in the point C.

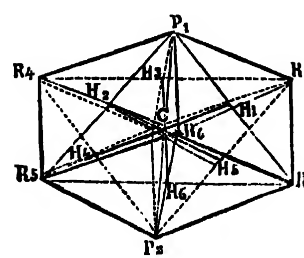


Fig. 251.

$H_1 H_4$, $H_2 H_5$, and $H_3 H_6$, will be the three equal axes of Professor Miller, and C H_1, C H_2, and C H_3, the three equal parameters.

Professor Miller refers the forms of the rhomboidal system to these three axes, equally inclined to one another, and with equal parameters. The inclination of these axes, and the length of the equal parameters, will differ for each particular substance, and depend upon its angular element. In the previous system of four axes, the inclination of the axes are the same for every substance; but the length of the unequal parameter will depend upon the angular element for each substance.

Both systems have their advantages. Professor Miller's is more consistent with

the method adopted in other systems, as all of them are referred to three axes, and his formulæ also possess the advantage of being readily translated into those of Haüy, and the modifications of his system by Brooke and Levy. The system of four axes, however, by its formulæ, gives a clearer view of the relations of the various forms to each other; and the axis in which the unequal parameter is taken is one of considerable importance, being the optic axis, in the case of every transparent substance crystallizing in the forms of the rhomboidal system. For these reasons we shall adopt the system of four axes, translating its formulæ into those of Professor Miller.

Parameters.—Take any arbitrary line C G_1 (Fig. 252) as the length of the three equal parameters. With C as a centre, and C G_1 as radius, describe the circle G_1 G_2 G_3.

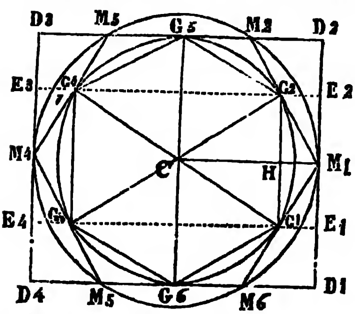


Fig. 252.

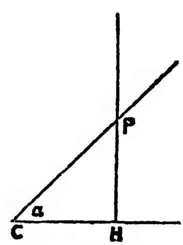


Fig. 253.

Take chords G_1G_2, G_2G_3, &c., G_6 G_1, each equal to CG_1. Join CG_2, CG_3, &c., C G_6. G_1 G_2 G_3, &c., G_6, will be a regular hexagon inscribed in the circle G_1 G_2 G_3.

G_1G_4, G_2G_5, and G_3G_6, will be three axes which lie in the same plane; C G_1, C G_2, C G_3, the three equal parameters.

To determine the fourth parameter which lies in the axis passing through C perpendicular to this plane, draw C H perpendicular to G_1 G_2. Then (Fig. 253) take C H equal CH (Fig. 252), and draw C P, making an angle P C H, equal to the angle given as the angular element for the particular substance whose parameters are to be obtained.

Through H draw H P perpendicular to C H, and meeting C P in P, H P will be the length of the fourth parameter.

To Draw the two Hexagonal Prisms.—Through each of the points G_1 G_2, &c., G_6 (Fig. 252), draw M_6 M_1, M_1 M_2, &c., M_5 M_6, perpendicular to C G_1, C G_2, &c., C G_6, meeting each other in the points M_1 M_2, &c., M_6. M_1 M_2 and M_6 is a regular hexagon circumscribing the circle G_1 G_2 G_3.

M_1 M_2, &c., M_6, is the hexagonal base of the ***hexagonal prism of the first order.*** G_1 G_2, &c., G_6, that of the ***hexagonal prism of the second order.***

Through M_1 and M_4 draw D_1 D_2 and D_4 D_3 parallel to G_6 G_3, meeting M_5 M_6 and M_1 M_2 produced in the points D_4 D_1 D_2 and D_3.

Join G_3 G_4 and G_1 G_5, and produce both ways to meet D_1 D_2 in E_2 and E_1, and D_3 D_4 in E_3 and E_4.

Then for the ***hexagonal prism of the first order*** (Fig. 249) draw D_1 D_4 equal D_1 D_4 (Fig. 252), and D_4 D_3, making an angle of about 30° with D_4 D_1. Draw D_1 D_2 parallel to D_4 D_3.

In D_1 D_4 (Fig. 249) take D_1 M_6, D_1 G_6, and D_1 M_5, equal to D_1 M_6, D_1 G_6, and D_1 M_5 (Fig. 252); also in D_1 D_2 take D_1 E_1, D_1 M_1, D_1 E_2, D_1 D_2 (Fig. 249), each equal the half of D_1 E_1, D_1 M_1, D_1 E_2, and D_1 D_2 (Fig. 252).

Take D_4 E_4, D_4 M_4, D_4 E_3, D_4 D_3 (Fig. 249), each equal to D_1 E_1, D_1 M_1, D_1 E_2, and D_1 D_2 of the same figure. Join D_2 D_3, and make D_2 M_2, D_2 G_3, D_2 M_3, each equal to D_1 M_6, D_1 G_6, D_1 M_5.

Join $M_1 M_6$, $M_1 M_2$, $M_3 M_4$, and $M_4 M_5$, also $E_1 E_4$, cutting $M_1 M_6$ in G_1, and $M_4 M_5$ in G_5, likewise join $E_1 E_2$, cutting $M_4 M_3$ in G_4, and $M_1 M_2$ in G_2.

Join $G_1 G_4$, $G_2 G_5$, and $G_3 G_6$, intersecting in the point C.

Through M_6 draw $M_6 B_6$ perpendicular to $M_6 M_5$. Take $M_6 B_6$ of any convenient length. Produce $B_6 M_6$ to B_{12}, make $M_6 B_{12}$ equal to $M_6 B_6$.

Through $M_1 M_2$, &c., M_5, draw $B_1 B_7$, $B_2 B_8$, &c., $B_5 B_{11}$, each parallel to $B_6 B_{12}$, and take $M_1 B_1$, $M_1 B_7$, &c., each equal to $M_6 B_6$.

Join $B_1 B_2$, $B_2 B_3$, &c., $B_6 B_1$, and $B_7 B_8$, $B_8 B_9$, &c., $B_{12} B_7$.

And the hexagonal prism of the first order will be constructed.

Through C draw $P_1 P_2$ parallel to $B_1 B_7$; take $C P_1$ and $C P_2$ equal to $M_1 B_1$. Then $P_1 P_2$, $G_1 G_4$, $G_2 G_5$, and $G_3 G_6$, are the four axes of this prism.

To draw the hexagonal prism of the second order, let $P_1 P_2$, $G_1 G_2 G_3$, &c., G_6 (Fig. 250), be determined in the same manner as in Fig. 249.

Through $G_1 G_2$, &c., G_6, draw $A_1 A_7$, $A_2 A_8$, &c., $A_6 A_{12}$, parallel to $P_1 P_2$, and $G_1 A_1$, $G_1 A_6$, $G_2 A_2$, &c., each equal to $C P_1$.

Join $A_1 A_2$, $A_2 A_3$, &c., and $A_7 A_8$, $A_8 A_9$, &c., and the hexagonal prism of the second order will be described.

$P_1 P_2$, $G_1 G_4$, $G_2 G_5$, and $G_3 G_6$, are the four axes of this prism.

Symbols.—Each face of the *hexagonal prism of the first order* cuts one of the axes in which the equal parameters are taken at distances equal to that parameter, and the two adjacent axes in the same plane at distances equal to twice the equal parameter, and is parallel to the axes in which the fourth unequal parameter is taken.

Thus the face $B_1 B_7 B_{12} B_6$ (Fig. 249), if produced, would cut the axis $C G_1$ in G_1, the axes $C G_6$, and $C G_2$ produced in points at a distance equal to twice $C G_1$ from C; it is also parallel to $C P_1$.

The symbol which represents these relations to the axes is 1, 2, ∞.

Naumann's symbol is ∞ P 2, Miller's $o \bar{1} 1$, Brooke and Levy's modification of Haüy d^1, or g^1, according as the rhomboid or hexagonal prism is taken for the primitive.

Each face of the *hexagonal prism of the second order* cuts two adjacent axes, in which the equal parameters are taken, at distances from the centre, equal to the equal parameter, and is parallel to the axis in which the unequal parameter is taken.

Thus (Fig. 250) the face of the prism, $A_1 A_2 A_8 A_7$, cuts the axes $C G_1$ and $C G_2$ in the points G_1 and G_2, $C G_1$ and $C G_2$ being both equal to the equal parameter, and is parallel to the axis CP_1.

The symbol which represents those relations to the axes is 1 1 ∞, Naumann's symbol is ∞ P, Miller's, 2 $\bar{1}$ $\bar{1}$, Brooke and Levy's, e^2 or m, according as the rhomboid or hexagonal prism is taken for the primitive.

The *basal pinacoids*, which inclose the prisms of both orders, are perpendicular to the axis C P, and parallel to the other axes; their symbol, therefore, is ∞ ∞ 1.

Naumann's symbol is o P, Miller's, 1 1 1, Brooke and Levy's a^1 or p, according as the rhomboid or hexagonal prism is taken for the primitive.

To describe a Net for the Hexagonal Prisms.—The regular hexagon $M_1 M_2$, &c., M_6 (Fig. 252), will form the top and bottom of the hexagonal prism of the first order, the hexagon $G_1 G_2$, &c., G_6, those of the hexagonal prism of the second order. Draw a rectangular parallelogram, having two of its opposite sides equal to the side of the regular hexagon, and the other two equal sides of any convenient length. Arrange two equal regular

hexagons, and six equal parallelograms, as in Fig. 253, and the net will be constructed.

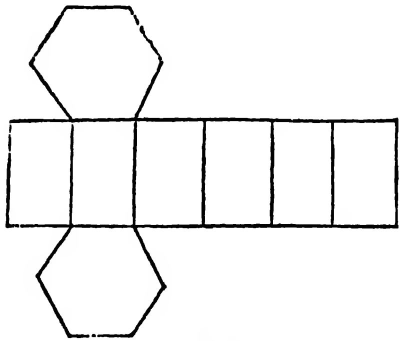


Fig. 254.

The hexagons being taken equal to M_1 M_2, &c., M_6, for the prism of the first order, and to G_1 G_2, &c., G_6, for that of the second order.

Minerals whose crystals present faces parallel to the hexagonal prism of the first order, whose symbol is 1 2 ∞, *Naumann* ∞ P 2, *Miller* 0 1 $\bar{1}$, *and Brooke and Levy* d^1 :—

Antimony.
Apatite.
Biotite.
Breithauptite.
Brucite.
Calamine.
Calcite.
Chabasie.
Chalybite.
Connellite.
Coquimbite.
Corundum.
Covelline.
Davyne.
Diallogite.
Dioptase.
Dolomite.
Emerald.
Endialyte.
Fluocerite.
Gmelinite.
Greenockite.
Hematite.
Hydrargillite.
Ice.
Ilmenite.
Kupfernickel.
Millerite.
Mimetite.
Molybdenite.
Nepheline.
Osmiridium.
Phenakite.
Plattnerite.
Polybasite.
Proustite.
Pyrargyrite.
Pyromorphite.
Pyrosmalite.
Pyrrhotine.
Quartz.
Ripidolite.
Spartalite.
Tourmaline.
Vanadinite.
Willemite.

Minerals whose crystals cleave parallel to this form, those printed in italics indicating that the cleavage is easy and perfect :—

Antimony.
Apatite.
Brucite.
Calcite.
Emerald.
Endialyte.
Greenockite.
Nepheline.
Phenakite.
Pyrosmalite.
Spartalite.

Minerals whose crystals present faces parallel to the hexagonal prism of the second order, whose symbol is $\bar{1}$ 1 ∞, *Naumann* ∞ P, *Miller* 2 $\bar{1}$ $\bar{1}$, *Brooke and Levy* e^2 :—

Apatite.
Calcite.
Chalybite.
Cinnabar.
Connellite.
Coquimbite.
Corundum.
Cronstedtite.
Davyne.
Emerald.
Endialyte.
Graphite.
Greenockite.
Hematite.
Hydrargillite.
Ilmenite.
Mesitine.
Millerite.
Mimetite.
Molybdenite.
Nepheline.
Phenakite.
Proustite.
Pyrargyrite.
Pyromorphite.
Pyrrhotine.
Quartz.
Ripidolite.
Susannite.
Tamarite.
Tellurium.
Tellurwismuth.
Tourmaline.
Willemite.

Cleavages parallel to the prism of the second order occur in—

Calcite.
Cinnabar.
Cronstedtite.
Pyrrhotine.
Quartz.
Tellurium.
Willemite.

Minerals whose crystals present faces parallel to the basal pinacoids, symbol ∞ ∞ 1, *Naumann* o P, *Miller* 1 1 1, *Brooke and Levy* a^1 :—

Alunite.
Ankerite.
Antimony.
Apatite.
Arsenic.
Biotite.
Bismuth.
Breithauptite.
Brucite.
Calamine.
Calcite.
Chabasie.
Chalybite.
Clintonite.
Chlorite.
Cinnabar.
Coquimbite.
Corundum.
Cronstedtite.
Covelline.
Davyne.
Diallogite.
Dolomite.
Emerald.
Eudialyte.
Fluocerite.
Gmelinite.
Graphite.
Greenockite.
Hematite.
Hydrargillite.
Ice.
Ilmenite.
Kupfernickel.
Levyne.
Mesitine.
Mimetite.
Molybdenite.
Nepheline.
Osmiridium.
Parasite.
Plattnerite.
Polybasite.
Proustite.
Pyrargyrite.
Pyromorphite.
Pyrosmalite.
Pyrrhotine.
Quartz.
Ripidolite.
Spartalite.
Stilpnomelane.
Susannite.
Tamarite.
Tellurium.
Tellurwismuth.
Tetradymite.
Tourmaline.
Vanadinite.
Willemite.
Xanthocone.

Cleavages parallel to the basal pinacoids occur in the following minerals :—

Alunite.
Antimony.
Apatite.
Arsenic.
Biotite.
Bismuth.
Brucite.
Calcite.
Clintonite.
Chlorite.
Corundum.
Cronstedtite.
Covelline.
Emerald.
Endialyte.
Graphite.
Greenockite.
Hematite.
Hydrargillite.
Ice.
Ilmenite.
Nepheline.
Osmiridium.
Parasite.
Polybasite.
Pyrosmalite.
Pyrrhotine.
Ripidolite.
Spartalite.
Stilpnomelane.
Susannite.
Tamarite.
Tellurium.
Tellurwismuth.
Tetradymite.
Willemite.
Xanthocone.

Position of the poles of the hexagonal prisms and basal pinacoid on the sphere of projection of the rhomboidal system.—With C as centre, and any convenient radius C M_1 describe the circle M_1 M_2 M_4.

Let $M_1 M_4$ and $G_2 G_5$ be any two diameters at right angles to each other.

Take arcs M_1 G_1, $G_2 M_2$, $G_2 M_3$, and M_4 G_3, each equal to 30°.

Through G_1, M_2, M_3 and G_3, draw the diameters G_1 G_4, M_2 M_5, M_3 M_6, and G_3 G_6.

Then C will represent the north pole of the sphere of projection, and the circle M_1 G_1 M_4 its equator.

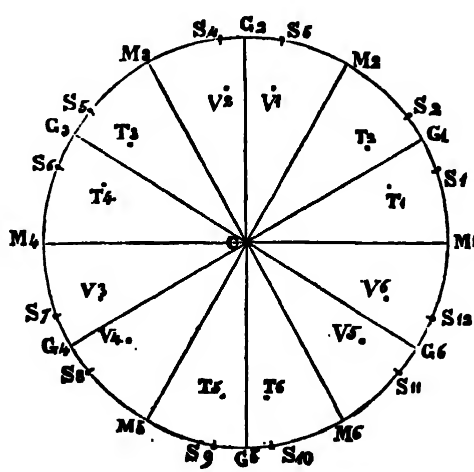


Fig. 255.

C will represent the pole of the upper *basal pinacoid*, G_1 G_2, &c.. G_6, the poles of the *hexagonal prism of the first order*, M_1 M_2, &c., M_6, the poles of the *hexagonal prism of the second order*, G_1 C G_4, G_2 C G_5, and G_3 C G_6, the zones in which the poles of the *six-faced pyramids of the first order* lie, and M_1 C M_4, M_2 C M_5, and M_3 C M_6, the zones in which the poles of the *six-faced pyramids of the second order* lie.

One pole of the *twelve-faced prism* will lie in each of the arcs M G, and one pole of the *double twelve-faced pyramid* in each compartment of the sphere bounded by the arcs C M, M G, and G C.

Double Six-Faced Pyramid of the First Order.— The double six-faced pyramid consists of two pyramids joined together, one on each side of a regular hexagonal base. It is bounded by twelve triangular faces, such as P_1 M_1 M_6 (Fig. 256), each face being an isosceles triangle. It has six *four-faced solid angles*, M_1 M_2, &c., M_6, and two *six-faced solid angles*, P_1 and P_2.

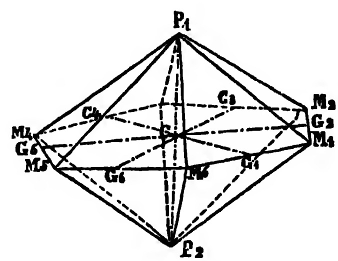


Fig. 256.

There are six equal edges, M_1 M_2, &c., which are the sides of the common hexagonal base, and twelve other edges, P_1 M_1, P_1 M_2, &c., equal to each other, but unequal to the former, which form the sides of the isosceles triangles. The hexagonal base of this pyramid is the hexagon circumscribing the circle described with one of the equal parameters for its radius.

To Draw the Double Six-faced Pyramid of the First Order.—Prick off the points M_1, M_2, &c., M_6, G_1, G_2, &c., G_6, P_1, P_2, and C, from Fig. 249.

Join M_1 M_2, M_2 M_3, &c., M_6 M_1, G_1 G_4, G_2 G_5, &c., and P_1 P_2.

Take C P_1 and C P_2, equal H P (Fig. 253), the unequal parameter.

Join P_1 M_1, P_1 M_2, &c., P_2 M_1, P_2 M_2, &c., and the pyramid will be constructed.

Axes.—The axes G_1 C_1, G_2 C_1, and G_3 C, in which the equal parameters lie, join the centres of the opposite edges of the hexagonal base of the pyramid; while the *fourth* axis, P_1 P_2, along which the unequal parameter is measured, joins the opposite apices of the pyramids.

Symbols.—Each face of the pyramid would, if produced, cut one of the axes in which the equal parameters are taken at the extremity of the parameter, the neighbouring axis in the hexagonal base at a distance from its centre twice that of the equal parameter, and the fourth axis perpendicular to the base at the extremity of the unequal parameter. Thus the face P_1 M_1 M_6, if produced, cuts the axis C G_1 at G_1, C G_6 at a distance from C equal twice C G_1, and C P_1 at P_1.

The symbol which expresses this relation to the axes is 1, 2, 1. Naumann's symbol for this form is P 2, or R ∞, Miller's *5*, 2, $\bar{1}$, Brooke and Levy's $d^{\frac{1}{2}}$ $d^{\frac{1}{4}}$ b^1, if the rhomboid, and a^2 if the hexagonal prism be taken as the primitive form.

Inclination of the Faces.—Let ϕ be the angle of inclination of the faces measured over the edges M_1 M_2, M_2 M_3, &c.; θ their inclination over the edges P_1 M_1, P_1 M_2, &c.; α the angular element; and λ the latitude of the faces measured from the pole C (Fig. 255), or the angle between the axis P_1 P_2, and the normals of the faces.

Then tan. $\lambda =$ cos. $30°$ tan. α cos. $\frac{\theta}{2} =$ sin. $30°$ sin λ and $\phi = 2\,\lambda$.

Position of the Poles on the Sphere of Projection.—The meridians of longitude in which the poles of this pyramid lie, will be those of 30°, 90°, and 150°, on both sides of M_1 C M_4; or four poles will lie in each zone G_1 C G_4, G_2 C G_5, and G_3 C G_6. Six poles will lie in the circle of latitude $\lambda°$ north, and six in the same parallel of south latitude.

Crystals whose Faces occur parallel to the Double Six-faced Pyramid of the first order, with the Latitude of their Poles on the sphere of projection.

Apatite	51° 44′.
Breithauptite . . .	56° 5.′
Emerald	40° 50′.
Quartz	47° 43′.

Double Six-faced Pyramids derived from the Pyramid of the First Order.—From the preceding pyramid others may be derived, by retaining the same base, and joining its angular points with points equidistant from C in the line P_1 P_2, or P_1 P_2 produced. Let Q_1 and Q_2 be these points. C Q_1 and C Q_2 are always some multiple m of the line C P. m may be any whole number or fraction.

When m is less than unity, or a proper fraction, Fig. 257 represents the pyramid which is more obtuse than Fig. 256, from which it is derived.

When m is greater than unity, Fig. 258 represents the pyramid which in this case is more acute than Fig. 256, from which it is derived.

Symbols.—Each face of this pyramid would, if produced, cut one of the axes in which the equal parameters are taken at the extremity of the parameter; the neigh-

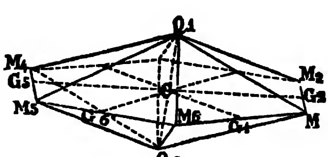


Fig. 257.

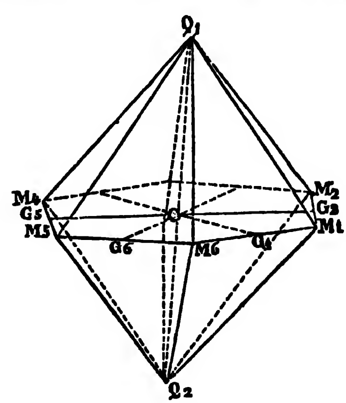


Fig. 258.

bouring axis in the hexagonal base, at a distance from its centre being twice that of the equal parameter, and the fourth axis perpendicular to the plane of the base of the pyramid, at a distance from the centre equal to m times the unequal parameter.

When m becomes infinitely great, the pyramid becomes the prism of the first order.

The symbol which expresses this relation to the axes is 1, 2, m. Naumann's symbol

for these pyramids is m P 2, or m R ∞; Miller's h, k, l; and Brooke and Levy's modification of Haüy $\frac{2}{a^{m}}$, if the hexagonal prism be taken as the primitive form. Their symbol, if the rhomboid be taken as the primitive form, will be given under each particular form.

Inclination of the Faces.—If λ be the angle of latitude of the faces, θ their inclination over the edges $Q_1 M_1$, $Q_2 M_2$, &c., ϕ over the edges $M_1 M_2$, $M_2 M_3$, &c., α the angular element for the substance,

Then $$\tan. \lambda = m \cos. 30° \tan. \alpha,$$

$$\cos. \frac{\theta}{2} = \sin. 30° \sin. \lambda, \text{ and } \phi = 2\lambda.$$

Position of the Poles of this Form on the Sphere of Projection.—The poles of these pyramids always lie in the same zones as the pyramid of the first order from which they are derived; six being in the circle of latitude $\lambda°$ north, and six in the same latitude south.

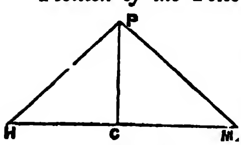


Fig. 259.

To describe the net for these Pyramids.—Draw C M_1 and C P (Fig. 259) perpendicular to each other. Take C M_1 equal to C M_1 (Fig. 252), C P equal C P_1 (Fig. 256), or C Q_1 (Figs. 257 and 258). Join P M_1.

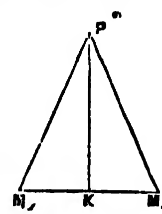


Fig. 260.

Then Fig. 260.—Draw $M_1 M_2$ equal $M_1 M_2$ (Fig. 252). On $M_1 M_2$ describe the isosceles triangle P $M_1 M_2$, having its sides P M_1 and P M_2 equal P M_1 (Fig. 259).

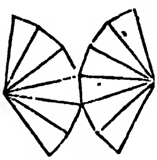


Fig. 261.

P $M_1 M_2$ will be a face of the pyramid, and twelve such faces, arranged as in Fig. 261, will form the required net.

Forms of the Double Six-faced Pyramids derived from the pyramid of the first order which occur in nature, together with the Latitude of their Faces.

The form 1, 2, $\frac{1}{3}$; $\frac{1}{3}$ P 2 Naumann; 2 3 1 Miller; a^{6} or $b^{1} b^{\frac{1}{2}} b^{\frac{1}{3}}$ Brooke and Levy.

Apatite	22° 55′.
Breithauptite	26° 22′.
Davyne	25° 53′.
* Greenockite	25° 28′.
Hematite	24° 22′.

The form 1, 2, $\frac{8}{3}$; $\frac{8}{3}$ P 2 Naumann; 3 7 $\bar{1}$ Milller; $a^{\frac{6}{4}}$ or $d^{\frac{1}{3}} d^{\frac{1}{7}} b^{\frac{1}{3}}$ Brooke and Levy.

Ripidolite	60° 00′.

The form 1, 2, $\frac{4}{3}$; $\frac{4}{3}$ P 2 Naumann; 1 3 $\bar{1}$ Miller; $a^{\frac{3}{2}}$ or e_3 Brooke and Levy.

Apatite	59° 24′.
Chalybite	47° 30′.
Corundum	61° 11′.
Emerald	49° 2′.
*Greenockite	62° 18′.
Hematite	61° 7′.
Ilmenite	61° 7′.
Mimetite	60° 0′.

Nepheline	62° 40′.
Osmiridium	62° 0′.
Parasite	82° 29′.
Phenakite	19° 17′.
Pyromorphite . . .	59° 32′.
Pyrosmalite	50° 47′.
Pyrrhotine	63° 25′.

The form 1, 2, $\frac{4}{3}$; $\frac{4}{3}$ P 2 Naumann; 1 2 0 Miller; a^3 or b^2 Brooke and Levy.

Apatite	40° 13′.
Calcite	29° 40′.
Chabasie	35° 15′.
Coquimbite	29° 0′.
Davyne	44° 8′.
Emerald	29° 57′.
Gmelinite	40° 4′.
*Greenockite . . .	43° 37′.
Hematite	42° 11′.
Kupfernickel	43° 25′.
Mimetite	40° 54′.
Molybdenite	Undetermined.
Nepheline . . .	44° 3′.
†Phenakite	11° 37′.
Plattnerite	Undetermined.
Polybasite	58° 30′.
Pyrargyrite	27° 43′.
Pyromorphite . . .	40° 22′.
Pyrosmalite	31° 30′.
Pyrrhotine	63° 25′.

Mimetite and Pyromorphite cleave parallel to this form.

The form 1, 2, $\frac{14}{9}$; $\frac{14}{9}$ P 2 Naumann; 3 10 $\bar{4}$ Miller; $a^{\frac{9}{5}}$ or $d^{\frac{1}{4}}$ $d_{\frac{1}{10}}$ $b^{\frac{1}{4}}$ Brooke and Levy.

Corundum	64° 45′.

The form 1, 2, 2; 2 P 2 Naumann; 1 4 $\bar{2}$ Miller; a^1 or d^1 $d^{\frac{1}{3}}$ $b^{\frac{1}{4}}$ Brooke and Levy.

Apatite	68° 29′.
Biotite	78° 8′.
Corundum	69° 51′.
Quartz	65° 33′.

The form 1, 2, $\frac{7}{3}$; $\frac{7}{3}$ P 2 Naumann; 2 9 $\bar{5}$ Miller; $a_{\frac{3}{17}}$ or $d^{\frac{1}{2}}$ $d^{\frac{1}{4}}$ $b^{\frac{1}{5}}$ Brooke and Levy.

Corundum	72° 31′.

The form 1, 2, $\frac{8}{3}$; $\frac{8}{3}$ P 2 Naumann; 1 5 $\bar{3}$ Miller; $a^{\frac{3}{4}}$ or d^1 $d^{\frac{1}{4}}$ $b^{\frac{1}{3}}$ Brooke and Levy.

Biotite	81° 3′.
Calcite	66° 18′.
Corundum	74° 36′.
*Greenockite . . .	75° 18′.
Mimetite	73° 54′.
Pyromorphite . . .	73° 37′.
Spartalite . . .	60° 34′.

The form 1, 2, $\frac{10}{3}$; $\frac{10}{3}$ P 2 Naumann; 1 6 4 Miller; $a^{\frac{3}{8}}$ or $d^1 d^{\frac{1}{6}}$ $b^{\frac{1}{4}}$ Brooke and Levy.

Hematite	77° 33′.
Ilmenite	77° 33′.

The form 1, 2, 4; 4 P 2 Naumann; $17\bar{5}$ Miller; $a^{\frac{1}{2}}$ or $d^1 d^{\frac{1}{7}}$ $b^{\frac{1}{5}}$ Brooke and Levy.

Apatite	78° 51′.
Biotite	84° 0′.
Calcite	73° 41′.
Corundum	79° 36′.
Hematite	79° 45′.

The form 1, 2, 5; 5 P 2 Naumann; 2, 17, $\overline{13}$ Miller; $a^{\frac{2}{5}}$ or $d^{\frac{1}{2}}$ $d^{\frac{1}{7}}$ $b^{\frac{1}{13}}$ Brooke and Levy.

Emerald	76° 58′.

The form 1, 2, $\frac{16}{3}$; $\frac{16}{3}$ P 2 Naumann; 1 9 $\bar{7}$ Miller; $a^{\frac{3}{8}}$ or $d^1 d^{\frac{1}{9}}$ $b^{\frac{1}{7}}$ Brooke and Levy.

Corundum	82° 10′.

The form 1, 2, 8; 8 P 2 Naumann; 1, 13, $\overline{11}$ Miller; $a^{\frac{1}{4}}$ or $d^1 d^{\frac{1}{13}}$ $b^{\frac{1}{11}}$ Brooke and Levy.

Corundum	84° 45′.

The forms of Greenockite, marked thus *, are sometimes hemihedral, with parallel faces; that of Phenakite, marked †, hemihedral, with inclined faces. The hemihedral forms, with parallel faces, are *rhomboids;* those with inclined faces, double *three-faced pyramids.*

Double Six-faced Pyramid of the Second Order.—The double six-faced pyramid of the second order is the same form of solid as the pyramid of the first order, and differs from it only in its position and relation to the axes of the system. The base of this pyramid, G_1 G_2, &c., G_6 (Fig. 262) is the hexagon G_1 G_2, &c., G_6 (Fig. 252) inscribed in the circle whose radius, C G_1, is equal to one of the equal parameters.

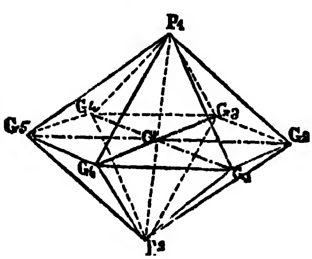


Fig. 262.

To Draw the Double Six-faced Pyramid of the Second Order.—Prick off the points G_1 G_2, &c., G_6, P_1 C_1 P_2, from Fig. 250. Take C P_1 and C P_2, equal H P (Fig. 253), the unequal parameter. Join P_1 G_1, P_1 G_2, &c., and the pyramid will be constructed.

Axes.—The axis P_1 P_2, in which the unequal parameter is taken, joins the opposite six-faced solid angles P_1 and P_2; while the axes in which the equal parameters are taken, such as G_1 G_4, join the opposite four-faced solid angles. Each face, therefore, of this pyramid cuts three axes at the extremities of their parameters.

Symbols.—The symbol which expresses the above relation of the faces of this pyramid to its axis is 111.

Naumann's symbol for this form is P. Miller, Brooke, and Levy do not treat this pyramid as a distinct form, but regard it as a combination of the two equal rhomboids which are its parallel hemihedral forms.

Inclination of the Faces.—Let ϕ be the angle of inclination of the faces measured over

the edges $P_1 G_1$, $P_2 G_2$, &c., θ their inclination over the edges $G_1 G_2$, $G_2 G_3$, &c., a the angular element.

$$\theta = 2\, a \qquad \cos.\ \frac{\phi}{2} = \frac{1}{2} \sin.\ a.$$

Position of the Poles on the Sphere of Projection.—The poles of the faces of this pyramid lie in the meridians of 0°, 60°, and 120°, six in the circle of latitude $a°$ north, and six in the same circle of south latitude; or four poles lie in each of the zones $M_1 C M_4$, $M_2 C M_5$, and $M_3 C M_6$ (Fig. 255).

Double Six-faced Pyramids derived from the Pyramid of the Second Order.—Retaining the same base, other pyramids may be derived from that of the second order by taking points Q_1 and Q_2 in C P or C P produced, such that C Q_1 or C Q_2 is equal to m times C P_1 (Fig. 262); m being a whole number or fraction greater than unity for the pyramid Fig. 264, and less than unity for Fig. 263.

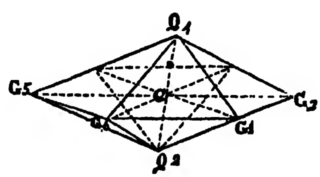


Fig. 263.

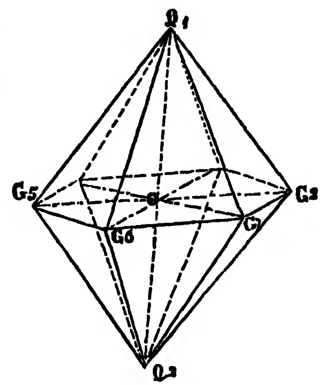


Fig. 264.

When m becomes infinitely great, the pyramid becomes the prism of the second order.

Symbols.—The symbol for these pyramids is 11 m, Naumann's m P.

Inclination of the Faces.—If ϕ be the angle of inclination of the faces measured over the edges $Q_1 G_1$, $Q_2 G_1$, &c., θ over the edges $G_1 G_2$, $G_2 G_3$, &c., a the angular element of the substance, and λ the inclination of the normals of the faces to $Q_1 Q_2$, or their latitude on the sphere of projection,

$$\tan.\ \lambda = m \tan.\ a \quad \theta = 2\ \lambda, \text{ and } \cos.\ \frac{\phi}{2} = \frac{1}{2} \sin.\ \lambda.$$

Position of the Poles on the Sphere of Projection.—The poles of the faces of these pyramids lie in the meridians of 0°, 60°, and 120°, six for each pyramid in the circle of latitude $\lambda°$ north, and six in the same circle of south latitude; or four poles lie in each of the zones $M_1 C M_4$, $M_2 C M_5$, and $M_3 C M_6$ (Fig. 255).

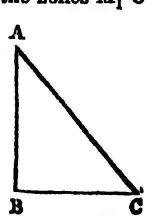


Fig. 265.

Nets for these Pyramids.—Take B C (Fig. 265), equal to C G_1 (Fig. 252). Draw B A perpendicular to B C. Take A B equal to C Q (Figs. 262 or 263); that is, equal to m times the unequal parameter. Join A C.

Then (Fig. 266) draw $G_1 G_2$ equal $G_1 G_2$ (Fig. 252); on it describe the isosceles triangle P G_1 G_2, having the sides P G_1 and P G_2 equal A C (Fig. 265).

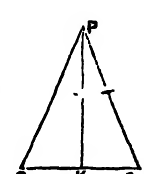


Fig. 266.

P G_1 G_2 is a face of the pyramid; and twelve such faces, arranged as in Fig. 261, will form the required net.

These pyramids occur so seldom, as homohedral or perfect forms in nature, that when they do so, they are regarded as combinations of the two hemihedral forms derived from them; we shall therefore describe them under their hemihedral forms.

Rhomboid.—The rhomboid may be considered as a hemihedral form with parallel faces of the double six-faced pyramid. The positive rhomboid (Fig. 267) is derived

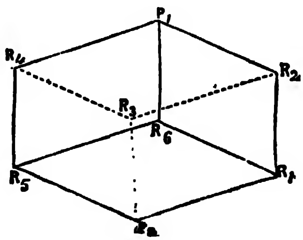


Fig. 267.

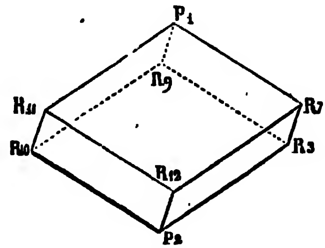


Fig. 268.

from the pyramid Fig. 262 by producing the faces $P_1\ G_1\ G_2$, $P_1\ G_3\ G_4$, $P_1\ G_5\ G_6$, $P_2\ G_1\ G_6$, $P_2\ G_2\ G_3$, and $P_2\ G_4\ G_5$ to meet one another. The negative rhomboid (Fig. 268) is formed by producing the other six faces of the pyramid.

The rhomboid is bounded by six equal faces, each of which, such as $P_1\ R_6\ R_1\ R_2$, are rhombs; that is, four-sided figures, with equal sides and opposite angles, but all the angles not equal. It has twelve equal edges, two *three-faced solid angles*, P_1 and P_2 (Figs. 267 and 268), formed by the union of three equal angles of the rhombic faces, and six *three-faced solid angles*, $R_1\ R_2$, &c. (Fig. 267), $R_{10}\ R_{11}$, &c. (Fig. 268), formed by the union of two equal angles of the rhombic faces with an unequal one.

To draw the Rhomboid.—Though the Rhomboid is derived from the double six-faced pyramid as its hemihedral form, and might be constructed from that figure by producing its faces, it is more easily obtained from the hexagonal prism of the first order.

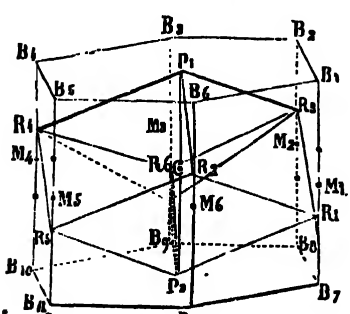


Fig. 269.

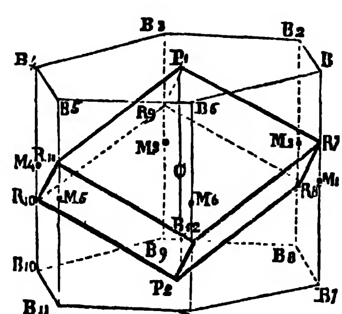


Fig. 270.

For Figs. 269 and 270, prick off from Fig. 249 all the points marked P C B and M. Take P C and $B_1\ M_1$, $B_2\ M_2$, &c., in both Figs. equal to the unequal parameter P C (Fig. 262), as determined for the particular substance whose rhomboid is to be drawn. Join all the B's and $P_1\ C\ P_2$.

Then for the positive rhomboid (Fig. 269), take $R_6\ M_6$ equal one-third of $M_6\ B_6$,

$M_1 R_1$ one-third of $M_1 B_7$, and so on, taking care that the points R are alternately above and below the points M.

Join P_1 with R_6, R_2 and R_4; and P_2 with R_1, R_3 and R_5; and $R_6 R_1 R_2 R_3 R_4 R_5$ and R_6, and the positive rhomboid will be constructed.

The negative rhomboid is constructed by taking M R one-third of M B alternately above and below M, as shown in Fig. 270, and joining the points B and R.

Symbols.—The symbol for the rhomboids derived from the pyramid whose symbol is 111, is $+\left[\frac{111}{2}\right]$ and $-\left[\frac{111}{2}\right]$, Naumann's symbol is $+\frac{P}{2}$ and $-\frac{P}{2}$ or $+$ R and $-$ R.

Miller's symbol for the *positive rhomboid* is 100, Brooke and Levy's P, if that rhomboid be taken as the primative form, $\frac{1}{2}(b^1)$ if the hexagonal prism be chosen for the primative.

Miller's symbol for the *negative rhomboid* is $\bar{1}\,2\,2$, Brooke and Levy's $\acute{e}^{\frac{1}{2}}$ or $\frac{1}{2}(b^1)$, according as the rhomboid or the hexagonal prism are taken as the primative form.

Inclination of the Faces of the Rhomboid.—If θ be the angles of inclination over any of the edges P R (Figs. 267 and 268), ϕ over the edges R R, and α the angular element.

$$\cos.\frac{\theta}{2} = \sin.\ 60\ \sin.\ \alpha \quad \text{and}\ \phi = 180° - \theta.$$

α is the latitude of the faces of the rhomboids on the sphere of projection.

Poles of the Rhomboids on the Sphere of Projection.—The poles of the positive rhomboid on the northern half of the sphere of projection (Fig. 255), are the points where

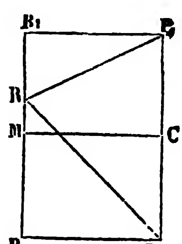


Fig. 271.

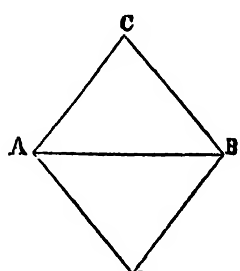


Fig. 272.

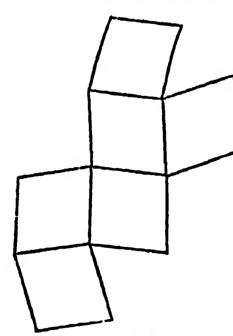


Fig. 273.

the circle of latitude, α, cuts the meridian C M_1, C M_3 and C M_5, the poles of the negative rhomboid where the same circle cuts the meridians C M_2, C M_4, and C M_6.

Nets for the Rhomboids.—Take C M (Fig. 271) equal C M (Fig. 252), draw P_1 C P_2 perpendicular to M C_1, take C P_1 and C P_2 equal C P_1 (Fig. 269 or 270).

Through M draw B_1 B_7 parallel to P_1 P_2 and through P_1 and P_2, P_1 B_1 and P_2 B_7 parallel to C M.

Take R M one-third of B_1 M. Join P_1 R and R P_2.

Then (Fig. 272) draw A B equal R P_2 (Fig. 271), on A B describe an isosceles triangle A C B, having its sides A C, B C equal P_1 R (Fig. 271). Describe a similar and equal triangle A D B on the other side of A B. The figure C A D B will be a face of the rhomboid, and six such faces, arranged, as in Fig. 273, will form the required net.

Faces parallel to those of the Positive Rhomboid occur in nature in the following substances. The angles are those of the inclinations of their faces θ and ϕ. The angle of their latitude, being the same as the angular element, is not given.

Alunite	92° 50′; 87° 10′.
Ankerite	106° 12′; 73° 48′.
Antimony	87° 35′; 92° 25′.
Apatite	88° 42′; 91° 18′.
Arsenic	85° 41′; 94° 19′.
Biotite	71° 4′; 108° 56′.
Bismuth	87° 40′; 92° 20′.
Breunnerite	107° 23′; 72° 37′.
Calamine	107° 40′; 72° 20′.
Calcite	105° 5′; 74° 55′.
Chabasie	94° 46′; 85° 14′.
Chalybite	106° 60′; 73° 0′.
Cinnabar	71° 48′; 108° 12′.
Corundum	86° 4′; 93° 56′.
Cronstedtite	Undetermined.
Diallogite	106° 51′; 73° 9′.
Dioptase	95° 54′; 84° 6′.
Dolomite	106° 15′; 73° 45 .
Emerald	104° 34′; 75° 26′.
Eudialyte	73° 30′; 106° 30′.
Gmelinite	Doubtful.
Hematite	86° 10′; 93° 50′.
Ilmenite	86° 10′; 93° 50′.
Levyne	106° 4′; 73° 56′.
Magnesite	107° 29′; 72° 31′.
Mesitine	107° 14′; 72° 46′.
Millerite	144° 8′; 35° 52′.
Mimetite	86° 48′; 93° 12′.
Nitratine	106° 33′; 73° 27′.
Phenakite	116° 40′; 63° 20′.
Proustite	107° 50′; 72° 10′.
Pyrargyrite	106° 42′; 73° 18′.
Pyromorphite	88° 28′; 91° 32′.
Pyrrhotine	82° 40′; 97° 20′.
Quartz	94° 15′; 85° 45′.
Ripidolite	75° 22′; 104° 22′.
Spartalite	116° 30′; 63° 30′.
Susannite	72° 30′; 107° 30′.
Tamarite	69° 48′; 110° 12′.
Tellurium	86° 2°; 93° 58′.
Tetradymite	66° 40′; 113° 20′.
Tourmaline	133° 8′; 46° 52′.
Willemite	128° 30′; 51° 30′.
Xanthocone	63° 18′; 116° 42′.

Cleavages parallel to the positive Rhomboid occur in the following minerals, the cleavage being perfect in those printed in italics.

Alunite.	*Diallogite.*	*Mesitine.*	*Pyrargyrite.*
Ankerite.	*Dolomite.*	*Millerite.*	Quartz.
Calcite.	Eudialyte.	*Nitratine.*	*Tourmaline.*
Chabasie.	Hematite.	Phenakite.	*Willemite.*
Chalybite.	Ilmenite.	Proustite.	*Xanthocone.*
Corundum.	*Magnesite.*		

Cronstedtite, Phenakite, and Pyrargyrite present hemihedral forms of the six-faced pyramid with inclined faces. This form is a double three-faced pyramid.

Faces parallel to the negative Rhomboid occur in the following minerals.

Apatite	88° 42′;	91° 18′	Phenakite	116° 40′;	63° 20′
Calcite	105° 5′;	74° 55′	Pyromorphite	88° 28′;	91° 32′
Corundum	86° 4′;	93° 56′	Pyrrhotine	82° 40′;	97° 20′
Dioptase	95° 54′;	84° 6′	Quartz	94° 15′;	85° 45′
Emerald	104° 34′;	75° 26′	Ripidolite	75° 22′;	104° 22′
Hematite	86° 10′;	93° 50′	Susannite	72° 30′;	107° 30′
Millerite	144° 8′;	35° 52′	Tellurium	86° 2′:	93° 58′
Mimetite	86° 48′;	93° 12′			

Millerite and Quartz are the only minerals which cleave parallel to the negative rhomboid, the cleavage of the first being perfect.

Rhomboids may be derived from each of the double six-faced pyramids (page 397), whose symbol is 11 m; to draw them we have only to make C P in Figs. 269 and 270 equal to m times the unequal parameter. Their nets may be constructed in a similar manner by making C P in Fig. 271 equal to the same quantity.

Symbols.—The symbols for these rhomboids will be $\left[\frac{11\ m}{2}\right]$, Naumann's $\frac{m\ P}{2}$ or m R, and Miller's $h\ k\ k$, where $m = \frac{h-k}{h+2\ k}$ is the relation existing between the numbers used by Naumann and Miller; Brooke and Levy's symbol will be $b^{\frac{1}{m}}$ when they take the hexagonal prism for their primitive form; when they regard the positive rhomboid as their primitive form, their symbols for the derived rhomboids will be given with each particular case.

Inclination of the Faces of the Rhomboids.—If λ be the latitude of the face of the rhomboid, and a its angular element, ϕ the angle of inclination over the edges PR, θ that over the edges RR (Figs. 267 and 268),

$$\tan.\ \lambda = m \tan.\ a, \quad \cos.\ \frac{\phi}{2} = m \sin.\ 60 \cos.\ \lambda \tan.\ a,$$
$$\text{and } \theta = 180° - \phi.$$

Rhomboids derived from the Double Six-faced Pyramids (p. 397), *whose Faces have been observed in nature, together with their Latitude on the Sphere of Projection.*

$\frac{1}{16}$ R Naumann; 655 Miller; $a^{\frac{5}{4}}$ Brooke and Levy.
Hematite . . 5° 36′

$-\frac{1}{8}$ R Naumann; 233 Miller; $a^{\frac{4}{3}}$ Brooke and Levy.
Hematite . . 11° 6′

$-\frac{1}{5}$ R Naumann; 122 Miller; $a^{\frac{1}{2}}$ Brooke and Levy.
Hematite . . 17° 26′

$\frac{1}{4}$ R Naumann; 211 Miller; a^2 Brooke and Levy.

Antimony	20° 40′	Cinnabar	33° 28′	Hematite	21° 25′	Pyrargyrite	12° 49′
Calcite	13° 52′	Eudialyte	31° 22′	Proustite	13° 3′	Tetradymite	42° 30′

Eudialyte cleaves parallel to this form.

$-\frac{1}{4}$ R Naumann; 255 Miller; $a^{\frac{2}{5}}$ Brooke and Levy.

Calcite	13° 52′	Hematite	21° 25′

$-\frac{2}{7}$ R Naumann; 133 Miller; $a^{\frac{1}{3}}$ Brooke and Levy.

Hematite . . 24° 9′

$\frac{1}{3}$ R Naumann; 522 Miller; $a^{\frac{5}{2}}$ Brooke and Levy.

Corundum	27° 41′	Cinnabar	41° 24′

$\frac{2}{5}$ R Naumann, 311 Miller; a^3 Brooke and Levy.

Cinnabar	46° 39′	Ilmenite	32° 7′

$\frac{1}{2}$ R Naumann; 411 Miller; a^4 Brooke and Levy.

Apatite	36° 13′	Hematite	38° 7′	Quartz	32° 25′
Corundum	38° 12′	Millerite	10° 46′	Tamarite	55° 51′

$-\frac{1}{2}$ R Naumann, 011 Miller; b^1 Brooke and Levy.

Ankerite	25° 42′	Calcite	26° 15′	Dolomite	25° 40′	Phenakite	20° 52′
Antimony	37° 2′	Chabasie	31° 22′	Eudialyte	50° 38′	Proustite	24° 53′
Apatite	36° 13′	Chalybite	25° 17′	Hematite	38° 7′	Pyrargyrite	24° 28′
Arsenic	38° 30′	Cinnabar	52° 54′	Ilmenite	38° 7′	Quartz	32° 25′
Bismuth	36° 58′	Diallogite	25° 23′	Mesitine	25° 11′	Tamarite	55° 51′
Breunnerite	25° 6′	Dioptase	31° 22′	Millerite	10° 46′	Tourmaline	14° 20′
Calamine	24° 58′						

Antimony, Bismuth, Chalybite, Diallogite, Hematite, Ilmenite, Proustite, Dioptase, and Millerite, cleave parallel to this form, the last two perfectly.

$\frac{5}{8}$ R Naumann; 611 Miller; a^6 Brooke and Levy.

Hematite . . 44° 27′

R Naumann; 711 Miller, a^7 Brooke and Levy

Calcite . . . 33° 20′

— R Naumann; 133 Miller, $e^{\frac{1}{3}}$ Brooke and Levy

Calcite . . . 38° 17′

— R Naumann, $\bar{2}$, 11, 11 Miller, $e^{\frac{7}{11}}$ Brooke and Levy

Calcite . . . 49° 49′

$-\frac{1}{8}$ R Naumann; 233 Miller, $e^{\frac{3}{2}}$ Brooke and Levy.

Calcite . . 50° 59′

$-\frac{1}{14}$ R Naumann, 455 Miller, $e^{\frac{5}{4}}$ Brooke and Levy

Arsenic	67° 16′	Calcite	55° 57′	Hematite	66° 59′	Proustite	54 18

$\frac{11}{17}$ R Naumann; 13, 2, $\bar{2}$ Miller, $e^{\frac{13}{2}}$ Brooke and Levy

Quartz . . . 61° 43′

$\frac{7}{4}$ R Naumann, 6, $\bar{1}$, $\bar{1}$ Miller, e^6 Brooke and Levy

Ripidolite . 75° 45′

2 R Naumann, $51\bar{1}$ Miller, e^5 Brooke and Levy

Apatite	71° 9′	Quartz	68° 31′

— 2 R Naumann; $\bar{1}11$ Miller; e^1 Brooke and Levy.

Antimony	71° 40′	Chabasie	67° 47′	Ilmenite	72° 20′	Ripidolite	77° 28′
Apatite	71° 9′	Chalybite	62° 7′	Levyne	62° 37′	Susannite	78° 56′
Biotite	79° 41′	Corundum	72° 22′	Phenakite	56° 44′	Tetradymite	82° 14′
Bismuth	71° 37′	Dolomite	62° 31′	Proustite	61° 41′	Tourmaline	45° 57′
Calamine	61° 46′	Eudialyte	78° 25′	Pyrargyrite	71° 13′	Willemite	49° 14′
Calcite	63° 7′	Hematite	72° 20′	Quartz	68° 31′	Xanthocone	[illegible]

Antimony, Bismuth, Levyne, and Tourmaline, cleave parallel to this form.

$\frac{5}{2}$ R Naumann; $4\bar{1}\bar{1}$ Miller, e^4 Brooke and Levy.

Hematite	75° 42′	Ilmenite	75° 42′	Ripidolite	78° 55′

$-\frac{5}{2}$ R Naumann; $\bar{8}77$ Miller; $e^{\frac{8}{7}}$ Brooke and Levy.

Calcite . . . 67° 56′

3 R Naumann; $7\bar{2}\bar{2}$ Miller; $e^{\frac{7}{2}}$ Brooke and Levy.

Quartz . . . 75° 18′

− 3 R Naumann; $\bar{5}44$ Miller; $e^{\frac{5}{4}}$ Brooke and Levy.

Calcite . . . 71° 20′ | Levyne . . 70° 57′ | Millerite . . 48° 47′

$-\frac{7}{2}$ R Naumann; $\bar{4}33$ Miller; $e^{\frac{4}{3}}$ Brooke and Levy.

Calamine . . 72° 56′ | Calcite . . . 73° 51′ | Quartz . . 77° 19′ | Tourmaline . 61° 4′

4 R Naumann; $3\bar{1}\bar{1}$ Miller; e^{3} Brooke and Levy.

Calamine . . 74° 58′	Dolomite . . 75° 25′	Pyrargyrite . 74° 38′	Spartalite . 71° 57′
Calcite . . . 75° 47′	Hematite . . 80° 57′	Quartz . . 78° 52′	Tourmaline . 64° 11′
Chalybite . . 75° 11′			

− 4 R Naumann; $\bar{7}55$ Miller; $e^{\frac{7}{5}}$ Brooke and Levy.

Calcite . . . 75° 47′

− 5 R Naumann; $\bar{3}22$ Miller; $e^{\frac{3}{2}}$ Brooke and Levy.

Calamine . . 77° 53′	Chalybite . 78° 3′	Ilmenite . . 82° 44′	Tourmaline . 68° 51′
Calcite . . . 78° 32′	Hematite . . 82° 44′	Pyrargyrite . 82° 11′	

$\frac{11}{2}$ R Naumann; $8\bar{3}\bar{3}$ Miller; $e^{\frac{8}{3}}$ Brooke and Levy.

Quartz . . 81° 51′

6 R Naumann; $1\bar{3}, \bar{5}, 5$ Miller; $e^{\frac{13}{5}}$ Brooke and Levy.

Quartz . . 82° 31′

− 7 R Naumann; $\bar{13}, 8, 8$ Miller; $e^{\frac{13}{8}}$ Brooke and Levy.

Quartz . . 83° 35′ | Susannite . 68° 38′

− 8 R Naumann; $\bar{5}33$ Miller; $e^{\frac{5}{3}}$ Brooke and Levy.

Calcite . . . 82° 47′

− 11 R Naumann; $\bar{7}44$ Miller; $e^{\frac{7}{4}}$ Brooke and Levy.

Quartz . . 85° 54′

Poles of the derived Rhomboids.—The poles of the positive rhomboids, that is of those rhomboids whose symbol, according to Naumann, is of the form mR, will be found by observing the points where the circle of latitude for λ° north cuts the meridians CM_1, CM_3, and CM_5 (Fig. 255), of the northern hemisphere of the sphere of projection, and where the same circle of south latitude cuts the meridians CM_2, CM_4, and CM_6 in the southern hemisphere. In the case of the negative rhomboids, or those whose symbol is — mR, the poles will be the intersection of the circle of north latitude λ, with the meridians CM_2 CM_4, and CM_6, and the same circle of south latitude with the meridian CM_1, CM_3, and CM_5.

Circle of Latitude on Sphere of Projection.—We here beg to call our readers' attention to an omission which we find we have made in the early part of our treatise. We ought to have warned our students that it is far more convenient for purposes of crystallography to reckon the degrees of latitude from the pole to the equator instead of from the equator to the pole. Strictly speaking, the angle which we have called the angle of latitude is the north or south polar distance. Our angle of latitude is always, therefore, the difference between 90° and the angle of latitude as reckoned on a celestial or terrestrial globe. This observation applies to the cubical and pyramidal systems.

The Right Prism on a Twelve-sided Base.—This prism, also called the *dihexagonal prism*, is a solid bounded by fourteen faces, twelve of which, such as L_1 L_7 G_7 G_1 (Fig. 274), are rectangular parallelograms, forming the sides of the prism; the other two, which terminate the prism, being irregular polygons, with twelve sides.

When this prism is considered an open form, its sides alone are taken for the planes of the prism, and the two faces which inclose it are considered faces of the same *basal pinacoids* which inclose the hexagonal prisms.

To Draw the Dihexagonal Prism.—Take any arbitrary line, CG_1 (Fig. 275), for one of the three equal parameters (as in Fig. 252, page 385); draw CG_2, CG_3, CG_4, &c.,

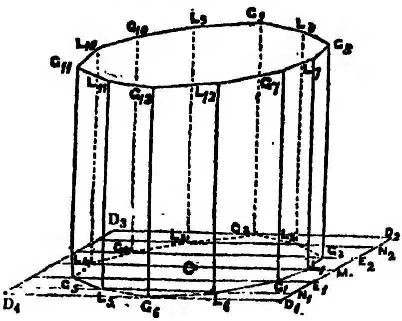


Fig. 274.

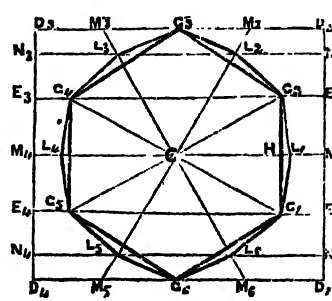


Fig. 275.

CG_6, each equal to CG_1, and inclined to each other at an angle of 60°. Join G_1 G_2, G_2 G_3, &c., G_5 G_6; G_1 G_2 G_3 &c. G_6 will be a regular hexagon, and G_1 G_4, G_2 G_5, and G_3 G_6 will represent the three axes of the hexagonal system in which the equal parameters are taken.

Draw CL_1, CL_2, CL_3, &c., CL_6 bisecting the angles G_1CG_2, G_2CG_3, &c., G_6CG_1. Then Fig. 276, draw the equilateral triangle CG_1 G_2 equal CG_1G_2 (Fig. 275); bisect G_1CG_2 by CH, produce CG_1 and CG_2 to K_1 and K_2; take CK_1 and CK_2 each equal n times CG_1, the symbol for the prism being $1\ n\ \infty$. Join G_1 K_2 and G_2 K_1 cutting CH produced in L. Lastly, in Fig. 275, take CL_1, CL_2, CL_3, &c., CL_6 each equal to CL (Fig. 276); join G_1 L_1, L_1 G_2, G_2 L_2, L_2 G_3, &c., and G_1 L_1 G_2 L_2 &c. L_6 G_1, will be the base of the prism. Through G_6 and G_3 draw the lines D_4 G_6 D_1 and D_3 G_3 D_2 parallel to L_4CL_1; take G_6 D_1 equal to any line greater than CL_1; G_6 D_4, G_3 D_2 and G_3 D_3, each equal to G_6 D_1.

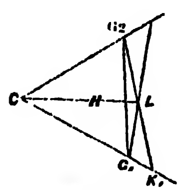


Fig. 276.

Join D_1 D_2 and D_4 D_3; produce L_3 L_6 to meet D_2 D_3 in M_3, and D_1 D_4 in M_6, and L_2 L_5 to meet D_2 D_3 in M_2, and D_1 D_4 in M_5.

Join L_5 L_6, G_5 G_1, G_4 G_2 and L_3 L_2, and produce these lines as well as L_4 L_1 to meet D_1 D_2 and D_4 D_3 in the points NE and M, as indicated in Fig. 275.

Draw D_1 D_4 (Fig. 274) equal D_1 D_4 (Fig. 275), and D_1 D_2 and D_4 D_3, each making an angle of 30°, to D_1 D_4. Take D_1 D_2 and D_4 D_3 equal to the half of D_1 D_2 and D_4 D_3 in Fig. 275.

In D_1 D_2 (Fig. 274) take D_1 N_1, D_1 E_1, D_1 N_1, D_1 E_2, D_1 N_2, each half of D_1 N_1, D_1 E_1, D_1 M_1, &c., respectively, in Fig. 275.

Through N_1, E_1, M_1, E_2 and N_2 draw N_1 N_4, E_1 E_4, M_1 M_4, E_2 E_3 and N_2 N_3 parallel to D_1 D_4. Take N_1 L_6, N_1 L_5, E_1 G_1, E_1 G_5, M_1 L_1, M_1 L_4, E_2 G_2, E_2 G_4, N_2 L_2, N_2 L_3, D_1 G_6 and D_2 G_3 respectively equal to N_1 L_6, N_1 L_5, E_1 G_1, E_1 G_5, &c. (Fig. 275). Draw G_6 G_{12} perpendicular to D_1 D_4, take G_6 G_{12} equal the height of the

prism intended to be represented; draw $L_6 L_{12}$, $G_1 G_7$, $L_1 L_7$, &c., as in Fig. 274, parallel and equal to $G_6 G_{12}$; join $G_{12} L_{12}$, $L_{12} G_7$, &c., and the ***right prism on a twelve-sided base*** will be drawn in isometrical perspective.

Axes.—$G_1 G_4$, $G_2 G_5$, and $G_3 G_6$ (Fig. 274) represent the three axes in which the equal parameters are taken. The fourth axis corresponds to the geometrical axis of the prism, and would be represented by a line drawn through C parallel to $G_6 G_{12}$.

Symbols.—Each face of the prism, if produced, would cut one of the three equal axes at a distance from the centre equal to the arbitrary unit, and an adjacent axis at n times this distance, and is parallel to the fourth axis.

The symbol which expresses this relation to the axes is $1\ n\ \infty$. Naumann's symbol for this form is ∞ P n; and Miller's $h\ k\ l$. $h\ k\ l$ and n may be obtained from each other by the formulæ

$$n = \frac{h - l}{h - k} \text{ and } h + k + l = o.$$

To describe a Net for the Right Prism on a Twelve-sided Base.—Draw two twelve-sided polygons, each equal to $G_1 L_1 G_2 L_2$, &c., $L_6 G_1$ (Fig. 275), and twelve rectangular parallelograms, each equal in breadth to $G_1 L_1$ (Fig. 275), and of a length equal to that of the prism intended to be represented. Arrange these fourteen figures as in Fig. 277, and the net will be constructed.

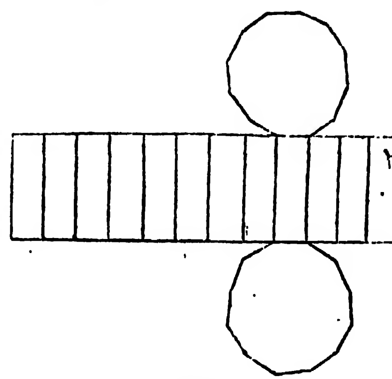


Fig. 277.

Position of the Poles of the Prism on the Sphere of Projection.—The poles of the faces of the ***dihexagonal prism*** always lie in the same zone, and that zone is the equator of the sphere of projection; S_1, S_2, S_3, S_4, &c., S_{12} (Fig. 255) represent these poles, the arcs $G_1 S_1$, $G_1 S_2$, $G_2 S_5$, $G_2 S_4$, &c., being equal to each other. Let θ be the angle M_1CS_1, or the longitude of the pole S_1 reckoning from M_1.

$$\tan\theta = \sqrt{3}\,\frac{n-1}{n+1} = \sqrt{3}\,\frac{k-l}{2h-k-l}.$$

Forms of the Dihexagonal Prism, parallel to which Faces have been observed in nature, with the Longitude of their Poles on the Sphere of Projection.

The form $1\ \frac{8}{7}\ \infty$; ∞ P $\frac{8}{7}$ Naumann; $5\ \bar{2}\ \bar{3}$ Miller; and $d^{\frac{1}{2}}\ d^{\frac{1}{3}}\ b^{\frac{1}{5}}$ Brooke and Levy; longitude 6° 35′ occurs in Corundum and *Dioptase.

The form $1\ \frac{6}{5}\ \infty$; ∞ P $\frac{6}{5}$ Naumann; $11\ \bar{4}\ \bar{7}$ Miller; $d^{\frac{1}{4}}\ d^{\frac{1}{7}}\ b^{\frac{1}{11}}$ Brooke and Levy; longitude 8° 57′ occurs in Quartz.

The form $1\ \frac{5}{4}\ \infty$; ∞ P $\frac{5}{4}$ Naumann; $3\ \bar{1}\ \bar{2}$ Miller; $d^{1}\ d^{\frac{1}{2}}\ b^{\frac{1}{3}}$ Brooke and Levy; longitude 10° 54′ occurs in *Apatite, Emerald, Hematite, *Phenakite, and Tourmaline.

The form $1\ \frac{4}{3}\ \infty$; ∞ P $\frac{4}{3}$ Naumann; $7\ \bar{2}\ \bar{5}$ Miller; $d^{\frac{1}{2}}\ d^{\frac{1}{5}}\ b^{\frac{1}{7}}$ Brooke and Levy; longitude 13° 54′ occurs in Calcite and *Dioptase.

The form $1\ \frac{7}{5}\ \infty$; $\infty\ P\ \frac{7}{5}$ Naumann; $4\ 1\ \bar{3}$ Miller; $d^1\ d^{\frac{1}{3}}\ b^{\frac{1}{4}}$ Brooke and Levy; longitude 16° 6′ occurs in Tourmaline.

The form $1\ \frac{3}{2}\ \infty$; $\infty\ P\ \frac{3}{2}$ Naumann; $5\ \bar{1}\ \bar{4}$ Miller; $d^1\ d^{\frac{1}{4}}\ b^{\frac{1}{5}}$ Brooke and Levy; longitude 19° 6′ occurs in *Apatite, *Dioptase, and Millerite.

The forms marked thus * are hemihedral, with parallel faces; the hemihedral form of this prism with parallel faces is a regular hexagonal prism, arising from the development of the alternate faces, and differs only from the prisms of the First and Second Order, in its position with regard to the axes.

Double Twelve-faced Pyramid.—The *double twelve-faced pyramid*, or, as it is generally called, the *dihexagonal pyramid*, consists of two pyramids joined together, one on each side of the dihexagonal base given in Fig 275. It is bounded by twenty-four equal and similar scalene triangles, it has twelve *four-faced solid angles* at the base of the pyramids, and two *twelve-faced solid angles*, one at each apex of the double pyramid.

This pyramid may be easily drawn; through C, in Fig 274, draw a line perpendicular to $L_1\ L_4$, take two points in this line equidistant from C, and each equal m times C P_1 (Fig. 256), and join these points with $G_1\ G_2$, &c., G_6 and $L_1\ L_2$, &c., L_6; m P n being the symbol of the pyramid.

This pyramid has never been observed alone, and scarcely ever in combination with other forms. When these latter occur, they may be regarded as the combination of the positive and negative scalenohedron derived from it.

Symbols.—Each face of the pyramid would, if produced, cut one of the axes in which the equal parameters are taken at the extremity of the parameter; the neighbouring axis in the hexagonal base at a distance from its centre n times that of the equal parameter, n being any fraction greater than one, and less than two; and the fourth axis, which is perpendicular to the base, at a distance from the centre m times that of the unequal parameter, m being a fraction or whole number equal to, greater, or less than unity. The symbol which expresses this relation is $1\ m\ n$. Naumann's symbol is $m\,\mathrm{P}\,n$, and Miller's $h\ k\ l$.

When m becomes infinitely great this pyramid passes into the *dihexagonal prism*, and when m is finite and n becomes equal to two, it passes into a *double six-faced pyramid*, derived from that of the *First Order*.

Position of the Poles on the Sphere of Projection.—Twelve poles lie in the same circle of north latitude and twelve in the same circle of south latitude, one pole lies within each spherical triangle C G M (Fig. 255), two poles lie in the same circle of latitude at equal angular distances on each side of every meridian C G, such as $T_1\ T_2$ on both sides of C G_1 and $V_1\ V_2$ on both sides of C G_2.

The formulæ for determining the latitude and longitude of these poles, from the symbols for their forms, as well as the relation between $m\ n\ h\ k$ and l, will be given under the description of the hexagonal scalenohedron.

Hexagonal Scalenohedron.—The *hexagonal scalenohedron* is a hemihedral form with parallel faces, derived from the *double twelve-faced pyramid* by producing half the faces of the upper pyramid taken in pairs to meet half the faces of the lower one which do not correspond to those taken from the upper. Thus the faces whose poles are T_1, V_6, T_3, V_2, V_4, and T_5 in the northern hemisphere of projection (Fig. 255), being produced to meet one another, and the faces whose poles are T_2, V_1, T_4, V_3, T_6, and V_5 of the southern hemisphere, will form the positive scalenohedron. The

twelve remaining faces if produced to meet each other will form the negative scalenohedron.

The hexagonal scalenohedron is bounded by twelve equal and similar scalene triangles, such as $K_1 R_1 R_2$ (Fig. 278), and $K_1 R_{12} R_7$ (Fig. 279); it has two six-faced solid

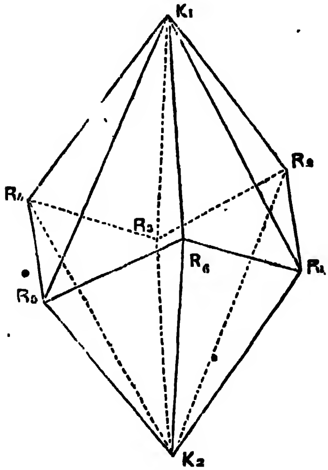


Fig. 278.

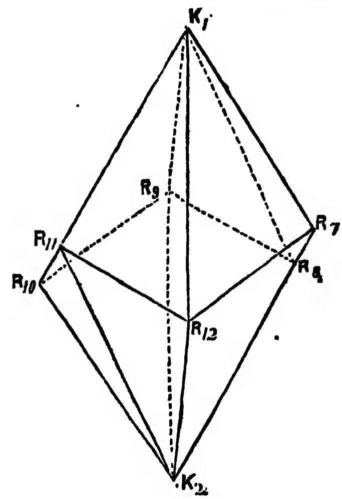


Fig. 279.

angles, K_1 and K_2 (Figs. 278 and 279), and six four-faced solid angles R_1, R_2, &c., R_6 (Fig. 278), and R_7, R_8, &c., R_{12} (Fig. 279). The four-faced solid angles are joined

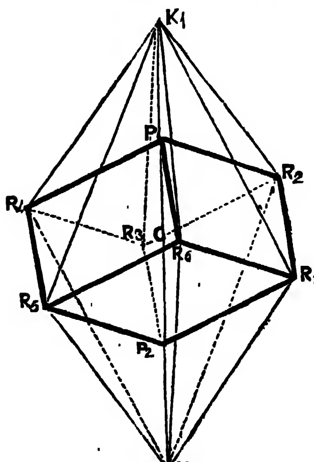


Fig. 280.

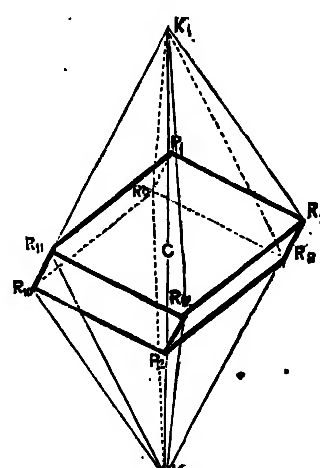


Fig. 281.

together by six equal edges, such as $R_1 R_2$ (Fig. 278,) and $R_{11} R_{12}$ (Fig. 279). These edges correspond to the edges of a rhomboid which may be inscribed in the scalenohe-

dron, with the same axes as the figure in which it is inscribed. The remaining twelve edges are equal in pairs, six being longer and six shorter, the longer and shorter edges joining the six-faced solid angles with the four-faced, alternately, as shown in Figs. 278 and 279.

To draw the Hexagonal Scalenohedron.—Though the hexagonal scalenohedron is derived from the double twelve-faced pyramid, by the development of half its faces, and might be constructed from that figure, it is more readily obtained from the positive or negative rhomboid which may be supposed to be inscribed in the scalenohedron.

Let two rhomboids (Figs. 280 and 281) be drawn as directed for Figs. 269 and 270. Produce C P_1 and C P_2 to K_1 and K_2 (Figs. 280 and 281), make C K_1 equal C K_2, then (Fig. 280) join $K_1 R_1$, $K_1 R_2$, &c., $K_1 R_6$; $K_2 R_1$, $K_2 R_2$, &c., $K_2 R_6$, also in Fig. 281 join $K_1 R_7$, $K_1 R_8$, &c., $K_1 R_{12}$; $K_2 R_7$, $K_2 R_8$, &c., $K_2 R_{12}$. Fig. 280 will give the positive, and Fig. 281 the negative scalenohedron, the combination of whose faces together would give the double twelve-faced pyramid.

Symbols. — If m P n be Naumann's symbol for the double twelve-faced pyramid from which the scalenohedron is derived, his symbol for the latter will be $+\left[\frac{m\ P\ n}{2}\right]$ or $-\left[\frac{m\ P\ n}{2}\right]$ according as the scalenohedron is positive or negative.

Naumann's symbol for the rhomboid inscribed in the scalenohedron whose symbol is $\left[\frac{m\ P\ n}{2}\right]$ is $\frac{m(2-n)}{n}$R; and C K is equal to $\frac{n}{2-n}$ times C P, hence Naumann chooses the arbitrary symbol $\frac{m(2-n)}{n}\ \mathrm{R}^{\frac{n}{2-n}}$ to represent the scalenohedron $\left[\frac{m\ P\ n}{2}\right]$.

To describe, therefore, the scalenohedron derived from the double twelve-faced pyramid m P n, we must describe the rhomboid $\frac{m(2-n)}{n}$R, produce C P_1 and C P_2 (Figs. 280 and 281), and make C K equal $\frac{n}{2-n}$ times C P.

Miller's symbol for the scalenohedron is $\mathrm{r}\{h\ k\ l\}$ where $m = \frac{h-l}{h+k+l}$ and $n = \frac{h-l}{h-k}$ are the relations between Naumann's and Miller's symbols for the same form.

Nets for the Scalenohedrons.

Describe the triangle $RP_1 P_2$ (Fig. 282) as in Fig. 271, to form the net of the rhomboid whose symbol is $\frac{m(2-n)}{n}$R. Bisect $P_1 P_2$ in C, produce CP_1 to K_1, make CK_1 equal $\frac{n}{2-n}$ times CP_1, produce CP_2 to K_2, and make CK_2 equal CK_1. Join K_1R and K_2R.

Then (Fig. 283) draw LM equal RP_1; on LM describe the triangle LMN, having its side LN equal RK_1, and its side MN equal RK_2. LMN will be a face of the scalenohedron $\frac{m(2-n)}{n}\ \mathrm{R}^{\frac{n}{2-n}}$, and twelve such faces, arranged as in Fig. 284, will form the net required.

Position of the Poles of the Hexagonal Scalenohedron on the Sphere of Projection.— If mPn be the symbol of the double twelve-faced pyramid from which the scalenohedron is derived, take an arc $M_1 S_1$, such that $\tan MS_1 = \sqrt{3}\frac{n-1}{n+1}$, mark off arcs $M_1 S_{12}$, $M_2 S_2$, $M_2 S_5$, &c., $M_6 S_{10}$, $M_6 S_{11}$, as in Fig. 255. Join CS_1, CS_2, CS_3, &c., CS_{12}. Let θ be the angular distance of a circle of latitude from C, such that $\tan\theta = \frac{m}{n}\sqrt{n^2-n+1}\tan a$, where a is the angular element for the substance of the crystal given in pages 385 and 386. Then this circle of latitude will cut the meridians CS_1, CS_2, CS_3, CS_4, &c., in the points T_1, T_2, V_1, V_2, &c., as in Fig. 255.

T_1, T_2, V_1, V_2, &c., will be the poles of the double twelve-faced pyramid on the sphere of projection.

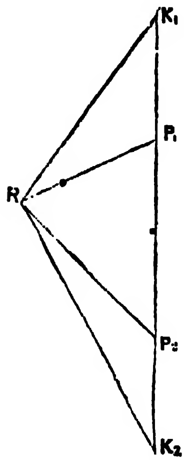


Fig. 282.

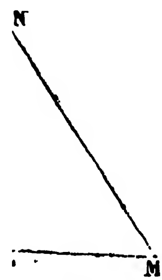


Fig. 283.

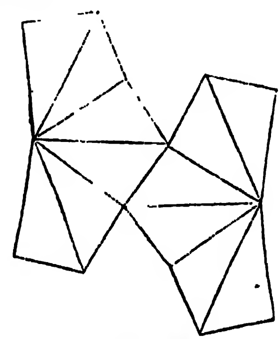


Fig. 284.

The poles $T_1\ V_2\ T_3\ V_4\ T_5\ V_6$ will be those of the positive, and $T_2\ V_1\ T_4\ V_3\ T_6\ V_5$ those of the negative scalenohedron on the northern sphere of projection.

The arc MS, which we may consider the longitude of the pole T, from the meridian CM_1, we shall represent by the symbol ϕ.

Faces of Scalenohedrons and other forms derived from the Double Twelve-faced Pyramids occur in Nature, in Crystals of the following substances.

The form $-13\ P\frac{13}{12}$, or $-11\ R^{\frac{13}{11}}$, Naumann; $\bar{8}\ 5\ 4$ Miller; $d^{\frac{1}{5}}\ d^{\frac{1}{4}}\ b^{\frac{1}{8}}$ Brooke and Levy. $\phi = 3°\ 58'$, in Quartz $\theta = 86°\ 24'$.

The form $\frac{6}{5}\ P\frac{12}{11}$, or $R^{\frac{6}{5}}$, Naumann; $11\ 0\ \bar{1}$ Miller; d^4 Brooke and Levy. $\varphi = 4°\ 18'$, in Dioptase $\theta = 54°\ 35'$.

The form $\frac{3}{2}\ P\frac{9}{8}$, or $\frac{7}{8}\ R^{\frac{9}{7}}$ Naumann; $7\ 1\ \bar{2}$ Miller; $d^{\frac{1}{7}}\ d^{1}\ b^{\frac{1}{2}}$ Brooke and Levy. $\phi = 5°\ 49'$, in Pyrargyrite $\theta = 52°\ 20'$.

The form $-\frac{8}{13}\ P\frac{8}{7}$, or $-\frac{6}{13}\ R^{\frac{4}{3}}$ Naumann; $22\ 19\ \bar{2}$ Miller; $d^{\frac{1}{22}}\ d^{\frac{1}{19}}\ b^{\frac{1}{2}}$ Brooke and Levy. $\phi = 6°\ 35'$, in Quartz $\theta = 36°\ 25'$.

The form $\frac{4}{3}\ P\frac{8}{7}$, or $R^{\frac{4}{3}}$, Naumann; $0\ 7\ \bar{1}$ Miller; d^7 Brooke and Levy. $\phi = 6°\ 35'$, in Dioptase $\theta = 56°\ 55'$.

The form $8\ P\frac{8}{7}$, or $6\ R^{\frac{4}{3}}$, Naumann; $16\ \bar{5}\ \bar{8}$ Miller; $d^{\frac{1}{5}}\ d^{\frac{1}{8}}\ b^{\frac{1}{16}}$ Brooke and Levy. $\phi = 6°\ 35'$, in Quartz $\theta = 84°\ 3'$.

The form $\frac{7}{8}$P$\frac{7}{6}$, or $\frac{5}{8}$R$^{\frac{7}{5}}$ Naumann; 7 1 0 Miller; b^7 Brooke and Levy. $\phi = 7° 35'$, in Calcite $\theta = 38° 58'$.

The form $\frac{7}{5}$ P$\frac{7}{6}$, or R$^{\frac{7}{5}}$ Naumann; 6 0 $\bar{1}$ Miller; d^6 Brooke and Levy. $\phi = 7° 35'$, in Calcite $\theta = 52° 18'$.

The form $\frac{6}{7}$P$\frac{6}{5}$, or $\frac{4}{7}$R$^{\frac{3}{2}}$ Naumann; 6 1 0 Miller; b^6 Brooke and Levy. $\phi = 8° 57'$, in Calcite $\theta = 38° 8'$.

The form $\frac{3}{2}$ P$\frac{6}{5}$, or R$^{\frac{3}{2}}$ Naumann; 5 0 1 Miller; d^5 Brooke and Levy. $\phi = 8° 57'$, in Calcite $\theta = 53° 57'$.

The form 6 P$\frac{6}{5}$, or 4 R$^{\frac{3}{2}}$ Naumann; 4 1 2 Miller; d^1 $d^{\frac{1}{2}}$ $b^{\frac{1}{4}}$ Brooke and Levy. $\phi = 8° 57'$, in Dolomite $\theta = 79° 25'$, and Quartz $\theta = 81° 57'$.

The form $\frac{10}{9}$ P$\frac{5}{4}$, or $\frac{2}{3}$ R$^{\frac{5}{3}}$ Naumann; $\bar{3}$ 7 5 Miller; $d^{\frac{1}{7}}$ $d^{\frac{1}{5}}$ $b^{\frac{1}{3}}$ Brooke and Levy. $\phi = 10° 54'$, in Corundum $\theta = 58° 2'$.

The form $\frac{5}{3}$ P$\frac{5}{4}$, or R$^{\frac{5}{3}}$ Naumann; 0 4 1 Miller; d^4 Brooke and Levy. $\phi = 10° 54'$, in Apatite $\theta = 69° 57'$, Calcite $\theta = 56° 26'$, Emerald $\theta = 56° 44'$, and Pyrargyrite $\theta = 54° 16'$.

The form $-\frac{5}{3}$ P$\frac{5}{4}$, or $-$ R$^{\frac{5}{3}}$ Naumann; 2 3 $\bar{2}$ Miller; $e_{\frac{3}{2}}$ Brooke and Levy. $\phi = 10° 54'$, in Apatite $\theta = 69° 57'$, and Emerald $\theta = 56° 44'$.

The form $-\frac{10}{3}$ P$\frac{5}{4}$, or $-$ 2 R$^{\frac{5}{3}}$ Naumann; $\bar{5}$ 3 5 Miller; $e_{\frac{3}{5}}$ Brooke and Levy. $\phi = 10° 54'$, in Calcite $\theta = 71° 39'$.

The form 5 P$\frac{5}{4}$, or 3 R$^{\frac{5}{3}}$ Naumann; 10 $\bar{2}$ 5 Miller; $d^{\frac{1}{2}}$ $d^{\frac{1}{5}}$ $b^{\frac{1}{10}}$ Brooke and Levy. $\phi = 10° 54'$, in Quartz $\theta = 80° 15'$.

The form $\frac{7}{4}$ P$\frac{14}{11}$, or R$^{\frac{7}{4}}$ Naumann; 11 0 $\bar{3}$ Miller; $d^{\frac{11}{3}}$ Brooke and Levy. $\phi = 11° 44'$, in Calcite $\theta = 57° 35'$.

The form $-\frac{9}{4}$ P$\frac{9}{7}$, or $-\frac{5}{4}$ R$^{\frac{9}{5}}$ Naumann; $\bar{4}$ 3 5 Miller; $d^{\frac{1}{3}}$ $d^{\frac{1}{5}}$ $b^{\frac{1}{4}}$ Brooke and Levy. $\phi = 12° 13'$, in Calcite $\theta = 63° 39'$.

The form $-\frac{4}{9}$ P $\frac{4}{3}$ or $-\frac{2}{9}$ R^2 Naumann; 11 14 2 Miller; $b^{\frac{1}{11}}$ $b^{\frac{1}{14}}$ $b^{\frac{1}{2}}$ Brooke and Levy. $\phi = 13° 54'$ in Quartz $\theta = 26° 58'$.

The form $\frac{4}{3}$ P $\frac{4}{3}$, or $\frac{2}{3}$ R^2 Naumann; 4 1 0 Miller; b^4 Brooke and Levy. $\phi = 13° 54'$ in Calcite $\theta = 35° 26'$ and Pyrargyrite $\theta = 33° 16'$.

The form 2 P $\frac{4}{3}$, or R^3 Naumann; 3 0 $\bar{1}$ Miller; d^3 Brooke and Levy. $\phi = 13° 54'$ in Calcite $\theta = 60° 39'$, Dioptase $\theta = 65° 33'$, Hematite $\theta = 46° 4'$, Phenakite $\theta = 53° 37'$, and Tourmaline $\theta = 42° 59'$.

The form $-$ 2 P $\frac{4}{3}$, or $-$ R^3 Naumann; 7 4 $\bar{5}$ Miller; $d^{\frac{1}{7}}$ $d^{\frac{1}{4}}$ $b^{\frac{1}{5}}$ Brooke and Levy. $\phi = 13° 54'$, in Dioptase $\theta = 65° 33'$.

The form 4 P $\frac{4}{3}$, or 2R^3 Naumann; 8 $\bar{1}$ $\bar{4}$ Miller; d^1 $d^{\frac{1}{4}}$ $b^{\frac{1}{8}}$ Brooke and Levy. $\phi = 13° 54'$ in Quartz $\theta = 77° 41'$.

The form $-$ 4 P $\frac{4}{3}$, or $-$ 2 R^3 Naumann; $\bar{2}$ 1 2 Miller; $e_{\frac{1}{2}}$ Brooke and Levy. $\phi = 13° 54'$, in Calcite $\theta = 74° 18'$, Phenakite $\theta = 70° 0'$, Quartz $\theta = 77° 41'$, and Tourmaline $\theta = 61° 47'$.

The form $-\frac{11}{3}$ P $\frac{11}{8}$, or $-\frac{5}{3}$ R$^{\frac{11}{5}}$ Naumann; $\bar{16}$ 17 8 Miller; $d^{\frac{1}{17}}$ $d^{\frac{1}{8}}$ $b^{\frac{1}{16}}$ Brooke and Levy. $\phi = 15° 18'$, in Quartz $\theta = 76° 31'$.

The form $\frac{7}{6}$ P$\frac{7}{6}$, or $\frac{1}{2}$ R$^{\frac{7}{5}}$ Naumann; 1 6 $\bar{1}$ Miller; e_6 Brooke and Levy. $\phi = 16° 6'$, in Apatite $\theta = 56° 44'$.

The form $-\frac{7}{8}P\frac{7}{5}$, or $-\frac{1}{4}R^{\frac{7}{3}}$ Naumann; 3 5 $\bar{2}$ Miller; $d^{\frac{1}{3}}\,d^{\frac{1}{5}}\,b^{\frac{1}{2}}$ Brooke and Levy. $\phi = 16^\circ\ 6'$, in Apatite $\theta = 56^\circ\ 44'$.

The form $-\frac{14}{9}P\frac{7}{5}$, or $-\frac{2}{3}R^{\frac{7}{3}}$ Naumann; $\bar{5}$ 5 9 Miller; $e_{\frac{9}{5}}$ Brooke and Levy. $\phi = 16^\circ\ 6'$, in Calcite $\theta = 53^\circ\ 52'$.

The form $\frac{7}{3}P\frac{7}{5}$, or $R^{\frac{7}{3}}$ Naumann; 0 5 $\bar{2}$ Miller; $d^{\frac{5}{2}}$ Brooke and Levy. $\phi = 16^\circ\ 6'$, in Apatite $\theta = 75^\circ\ 0'$, and Calcite $\theta = 64^\circ\ 2'$.

The form $-\frac{7}{3}P\frac{7}{5}$, or $-R^{\frac{7}{3}}$ Naumann; $\bar{3}$ 4 2 Miller; $d^{\frac{1}{2}}\,d^{\frac{1}{4}}\,b^{\frac{1}{3}}$ Brooke and Levy. $\phi = 16^\circ\ 6'$, in Apatite $\theta = 75^\circ\ 0'$ and Calcite $\theta = 64^\circ\ 2'$.

The form $-\frac{10}{3}P\frac{10}{7}$, or $-\frac{4}{3}R^{\frac{5}{2}}$ Naumann; 14 16 7 Miller; $d^{\frac{1}{16}}\,d^{\frac{1}{7}}\,b^{\frac{1}{14}}$ Brooke and Levy. $\phi = 17^\circ\ 0'$, in Quartz $\theta = 75^\circ\ 7'$.

The form $-\frac{3}{5}P\frac{3}{2}$, or $-\frac{1}{5}R^3$ Naumann; 0 2 3 Miller; $b^{\frac{3}{2}}$ Brooke and Levy. $\phi = 19^\circ\ 6'$, in Calcite $\theta = 27^\circ\ 34'$.

The form $\frac{3}{4}P\frac{3}{2}$, or $\frac{1}{4}R^3$ Naumann; 3 1 0 Miller; b^3 Brooke and Levy. $\phi = 19^\circ\ 6'$, in Calcite $\theta = 33^\circ\ 8'$, Phenakite $\theta = 26^\circ\ 45'$, Proustite $\theta = 31^\circ\ 32'$, and Pyrargyrite $\theta = 31^\circ\ 2'$.

The form $\frac{6}{5}P\frac{3}{2}$, or $\frac{2}{5}R^3$ Naumann; 5 1 1 Miller; e_5 Brooke and Levy. $\phi = 19^\circ\ 6'$, in Corundum $\theta = 59^\circ\ 1'$, Hematite $\theta = 58^\circ\ 57'$, and Pyrargyrite $\theta = 43^\circ\ 55'$.

The form $\frac{3}{2}P\frac{3}{2}$, or $-\frac{1}{2}R^3$ Naumann; $\bar{1}$ 1 2 Miller; e_2 Brooke and Levy. $\phi = 19^\circ\ 6'$, in Calcite $\theta = 52^\circ\ 33'$, Dioptase $\theta = 58^\circ\ 13'$, Hematite $\theta = 64^\circ\ 17'$, Phenakite $\theta = 45^\circ\ 14'$, Pyrargyrite $50^\circ\ 17'$, and Tourmaline $\theta = 34^\circ\ 22'$.

The form $\frac{15}{8}P\frac{3}{2}$, or $\frac{5}{8}R^3$ Naumann; 11 1 $\bar{4}$ Miller; $d^1\,d^{\frac{1}{11}}\,b^{\frac{1}{4}}$ Brooke and Levy. $\phi = 19^\circ\ 6'$, in Pyrargyrite $\theta = 56^\circ\ 24'$.

The form $-\frac{12}{5}P\frac{3}{2}$, or $-\frac{4}{5}R^3$ Naumann; 5 3 7 Miller; $d^{\frac{1}{3}}\,d^{\frac{1}{7}}\,b^{\frac{1}{5}}$ Brooke and Levy. $\phi = 19^\circ\ 6'$, in Calcite $\theta = 64^\circ\ 25'$.

The form $3P\frac{3}{2}$, or R^3 Naumann; 2 0 $\bar{1}$ Miller; d^2 Brooke and Levy. $\phi = 19^\circ\ 6'$, in Calcite $\theta = 69^\circ\ 2'$, Chalybite $\theta = 58^\circ\ 35'$, Dolomite $\theta = 68^\circ\ 32'$, Eudialyte $\theta = 81^\circ\ 11'$, Hematite $\theta = 76^\circ\ 28'$, Phenakite $\theta = 63^\circ\ 38'$, Proustite $\theta = 67^\circ\ 50'$, Pyrargyrite $\theta = 67^\circ\ 27'$, and Tourmaline $\theta = 53^\circ\ 49'$. Calcite has an imperfect cleavage parallel to this form.

The form $-3P\frac{3}{2}$, or $-R^3$ Naumann; $\bar{4}$ 2 5 Miller; $d^{\frac{1}{2}}\,d^{\frac{1}{5}}\,b^{\frac{1}{4}}$ Brooke and Levy. $\phi = 19^\circ\ 6'$, in Calcite $\theta = 69^\circ\ 2'$ and Quartz $\theta = 73^\circ\ 26'$.

The form $\frac{24}{5}P\frac{3}{2}$, or $\frac{8}{5}R^3$ Naumann; 15 $\bar{1}$ $\bar{9}$ Miller; $d^1\,d^{\frac{1}{9}}\,b^{\frac{1}{15}}$ Brooke and Levy. $\phi = 19^\circ\ 6'$, in Calcite $\theta = 76^\circ\ 32'$.

The form $-6P\frac{3}{2}$, or $-2R^3$ Naumann; $\bar{3}$ 1 3 Miller; $e_{\frac{1}{3}}$ Brooke and Levy. $\phi = 19^\circ\ 6'$, in Calcite $\theta = 79^\circ\ 9'$, Hematite $\theta = 83^\circ\ 8'$, and Pyrargyrite $\theta = 78^\circ\ 16'$.

The form $\frac{11}{3}P\frac{11}{7}$, or $R^{\frac{11}{3}}$ Naumann; 7 0 $\bar{4}$ Miller; $d^{\frac{7}{4}}$ Brooke and Levy. $\phi = 19^\circ\ 6'$, in Calcite $\theta = 72^\circ\ 30$.

The form $-2P\frac{8}{5}$, or $-\frac{1}{2}R^4$ Naumann; $\bar{3}$ 2 5 Miller; $d^{\frac{1}{2}}\,d^{\frac{1}{5}}\,b^{\frac{1}{3}}$ Brooke and Levy. $\phi = 19^\circ\ 6'$, in Calcite $\theta = 59^\circ\ 55'$.

The form $-\frac{8}{3}P\frac{8}{5}$, or $-\frac{2}{3}R^4$ Naumann; $\bar{10}$ 14 5 Miller; $d^{\frac{1}{14}}\,d^{\frac{1}{5}}\,b^{\frac{1}{10}}$ Brooke and Levy. $\phi = 21^\circ\ 47'$, in Quartz $\theta = 71^\circ\ 21'$.

The form $4P\frac{8}{5}$, or R^4 Naumann; 5 0 $\bar{3}$ Miller; $d^{\frac{5}{3}}$ Brooke and Levy. $\phi = 21^\circ\ 47'$, in Calcite $\theta = 73^\circ\ 51$.

The form $\frac{5}{4}$ P $\frac{5}{3}$, or $\frac{1}{4}$ R^5 Naumann; $4\ 1\ \bar{1}$ Miller; e_4 Brooke and Levy. $\phi = 23°\ 25'$, in Corundum $\theta = 59°\ 45'$, Emerald $\theta = 47°\ 24'$, and Hematite $\theta = 59°\ 41'$.

The form $-\frac{5}{4}$ P $\frac{5}{3}$, or $-\frac{1}{4}$ R^5 Naumann; $5\ 11\ \bar{4}$ Miller; $d^{\frac{1}{5}}\ d^{\frac{1}{11}}\ b^{\frac{1}{4}}$ Brooke and Levy. $\phi = 23°\ 25'$, in Emerald $\theta = 47°\ 24'$.

The form $-\frac{10}{7}$ P $\frac{5}{3}$, or $-\frac{2}{7}$ R^5 Naumann; $\bar{3}\ 3\ 7$ Miller; $e_{\frac{7}{3}}$ Brooke and Levy. $\phi = 23°\ 25'$, in Calcite $\theta = 50°\ 52'$.

The form $\frac{5}{3}$ P $\frac{5}{3}$, or $\frac{1}{3}$ R^5 Naumann; $\bar{4}\ 11\ 2$ Miller; $d^{\frac{1}{7}}\ d^{\frac{1}{11}}\ b^{\frac{1}{4}}$ Brooke and Levy. $\phi = 23°\ 25'$, in Quartz $\theta = 61°\ 33'$.

The form $-\frac{5}{2}$ P $\frac{5}{3}$, or $-\frac{1}{2}$ R^5 Naumann; $\bar{2}\ 1\ 3$ Miller; $d^1\ d^{\frac{1}{3}}\ b^{\frac{1}{2}}$ Brooke and Levy. $\phi = 23°\ 25'$, in Calcite $\theta = 65°\ 4'$, and Hematite $\theta = 73°\ 42'$.

The form 5 P $\frac{5}{3}$, or R^5 Naumann; $3\ 0\ \bar{2}$ Miller; $d^{\frac{3}{2}}$ Brooke and Levy. $\phi = 23°\ 25'$, in Calcite $\theta = 76°\ 55'$, Emerald $\theta = 77°\ 3'$, Proustite $\theta = 76°\ 7'$, Pyrargyrite $\theta = 75°\ 51'$, and Tourmaline $\theta = 66°\ 4'$.

The form -5 P $\frac{5}{3}$, or $-$ R^5 Naumann; $2\ 8\ \bar{7}$ Miller; $d^{\frac{1}{2}}\ d^{\frac{1}{8}}\ b^{\frac{1}{7}}$ Brooke and Levy. $\phi = 23°\ 25'$, in Emerald $\theta = 77°\ 3'$.

The form $-\frac{12}{5}$ P $\frac{12}{7}$, or $-\frac{2}{5}$ R^6 Naumann; $\bar{14}\ 22\ 7$ Miller; $d^{\frac{1}{22}}\ d^{\frac{1}{7}}\ b^{\frac{1}{14}}$ Brooke and Levy. $\phi = 24°\ 30'$, in Quartz $\theta = 69°\ 20'$.

The form $\frac{7}{10}$ P $\frac{7}{4}$ or $\frac{1}{10}$ R^7 Naumann; $7\ 3\ 0$ Miller; $b^{\frac{7}{3}}$ Brooke and Levy. $\phi = 25°\ 17'$, in Calcite $\theta = 37°\ 37'$.

The form $-\frac{7}{5}$ P $\frac{7}{4}$, or $-\frac{1}{5}$ R^7 Naumann; $\bar{2}\ 2\ 5$ Miller; $e_{\frac{5}{4}}$ Brooke and Levy. $\phi = 25°\ 17'$, in Calcite $\theta = 57°\ 1'$.

The form $\frac{7}{4}$ P $\frac{7}{4}$, or $\frac{1}{4}$ R^7 Naumann; $5\ 1\ \bar{2}$ Miller; $d^1\ d^{\frac{1}{5}}\ b^{\frac{1}{2}}$ Brooke and Levy. $\phi = 25°\ 17'$, in Pyrargyrite $\theta = 54°\ 9'$.

The form 7 P $\frac{7}{4}$, or R^7 Naumann; $4\ 0\ \bar{3}$ Miller; $d^{\frac{4}{3}}$ Brooke and Levy. $\phi = 25°\ 17'$, in Calcite $\theta = 82°\ 36'$, and Pyrargyrite $\theta = 79°\ 46'$.

The form $-\frac{9}{2}$ P $\frac{9}{5}$, or $-\frac{1}{2}$ R^9 Naumann; $5\ 1\ \bar{4}$ Miller; $d^1\ d^{\frac{1}{5}}\ b^{\frac{1}{4}}$ Brooke and Levy. $\phi = 26°\ 20'$, in Dolomite $\theta = 74°\ 58'$.

The form 9 P $\frac{9}{5}$, or R^9 Naumann; $5\ 0\ \bar{4}$ Miller; $d^{\frac{5}{4}}$ Brooke and Levy. $\phi = 26°\ 20'$, in Calcite $\theta = 82°\ 36'$.

The form 11 P $\frac{11}{6}$, or R^{11} Naumann; $6\ 0\ \bar{5}$ Miller; $d^{\frac{6}{5}}$ Brooke and Levy. $\phi = 27°\ 0'$, in Calcite $\theta = 83°\ 56'$.

The form 12 P $\frac{24}{13}$, or R^{12} Naumann; $13\ 0\ \bar{11}$ Miller; $d^{\frac{13}{11}}$ Brooke and Levy. $\phi = 27°\ 15'$, in Calcite $\theta = 84°\ 26'$.

Other forms derived from the Double Twelve-faced Pyramid.—If the faces of the upper pyramid, whose poles are marked by $T_1\ V_1\ T_3\ V_3\ T_5$ and V_5 (Fig. 255), are produced to meet the corresponding faces of the lower pyramid; the resulting form will be a *double six-faced pyramid* similar in form, but different in position to the double six-faced pyramids derived from those of the first and second order. The remaining twelve faces being produced to meet each other will produce a similar double *six-faced pyramid.*

From these *double six-faced pyramids, rhomboids and double three-faced pyramids* may be produced by producing half their faces to meet each other.

If the alternate faces of the upper pyramid, whose poles are $T_1\ V_1\ T_3\ V_3\ T_5$ and V_5

(Fig. 255), be produced to meet the faces of the lower pyramid corresponding to V_6 T_2 V_2 T_4 V_4 and T_6, the resulting figure will be a double *six-faced trapezohedron.*

Half the faces of this trapezohedron, namely those corresponding to T_1 T_3 and T_5, for the upper pyramid, and T_2 T_4 and T_6 for the lower, when produced to meet will form a *double three-faced trapezohedron.* This figure may also be formed by producing the alternate faces of the upper part of the scalenohedron to meet the alternate faces of the lower scalenohedron which do not correspond to them.

The double three-faced trapezohedron may be regarded as a *hemihedral* form of either the *double six-faced trapezohedron* or the *hexagonal scalenohedron,* and consequently a *tetartohedral form* of the double twelve-faced pyramid. The forms of quartz given under the head of scalenohedrons, generally present in their combinations this species of the *tetartohedral forms.*

PRINCIPAL COMBINATIONS OF THE RHOMBOHEDRAL SYSTEM.

Fig. 286. Combination of the *double six-faced pyramid of the second order,* with the *hexagonal prism of the second order. a,* faces of the negative rhomboid — R Naumann,

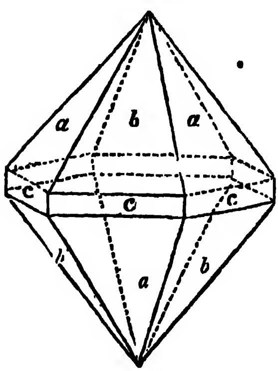


Fig. 286.

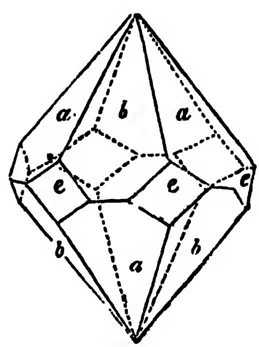


Fig. 287.

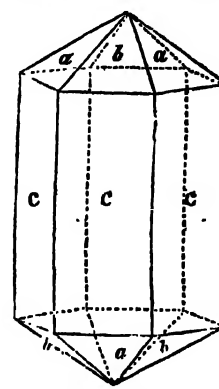


Fig. 288.

$\bar{1}$ 2 2 Miller, $e^{\frac{1}{2}}$ Brooke and Levy. *b,* faces of the negative rhomboid R Naumann, 1 0 0 Miller, and P Brooke and Levy. *c,* faces of the hexagonal prism of the second order, ∞ P Naumann, 2 $\bar{1}$ $\bar{1}$ Miller, and e^2 Brooke and Levy.

Fig. 287. Combination of the *double six-faced pyramid of the second order* with the *hexagonal prism of the first order. a,* faces of the *negative rhomboid. b,* faces of the *positive rhomboid. e,* faces of the hexagonal prism of the first order, ∞ P 2 Naumann, 0 1 $\bar{1}$ Miller, and d^1 Brooke and Levy.

Fig. 288. Combination of the *hexagonal prism of the second order* with the *double six-faced pyramid of the second order. a,* faces of negative rhomboid. *b,* faces of positive rhomboid. *c,* faces of hexagonal prism of the second order.

Fig. 289. Combination of two positive rhomboids. *r,* faces of the rhomboid whose symbols are R Naumann, 1 0 0 Miller, and P Brooke and Levy. *s,* faces of the rhomboid whose symbols are 2,R Naumann, 5 1 $\bar{1}$ Miller, e^5 Brooke and Levy.

Fig. 290. Combination of a positive and negative rhomboid. *r,* faces of the rhomboid 2 R Naumann, 5 $\bar{1}$ $\bar{1}$ Miller, e^5 Brooke and Levy. *s,* faces of the rhomboid — R Naumann, $\bar{1}$ 2 2 Miller, $e^{\frac{1}{2}}$ Brooke and Levy.

Fig. 291. Combination of a scalenohedron and rhomboid. *r*, faces of the rhomboid

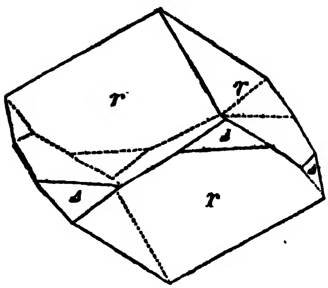


Fig. 289.

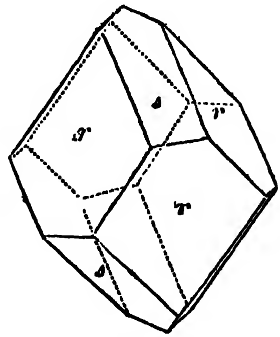


Fig. 290.

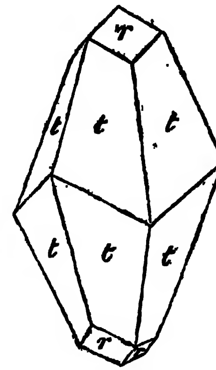


Fig. 291.

R Naumann, 1 0 0 Miller, P Brooke and Levy. *t*, faces of the scalenohedron, R^3 Naumann, 2 0 $\bar{1}$ Miller, d^2 Brooke and Levy.

Fig. 292. Combination of the positive rhomboid with the hexagonal prism of the first order. *r*, faces of the rhomboid. *e*, faces of the prism.

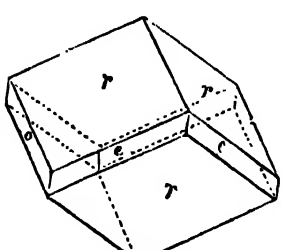


Fig. 292.

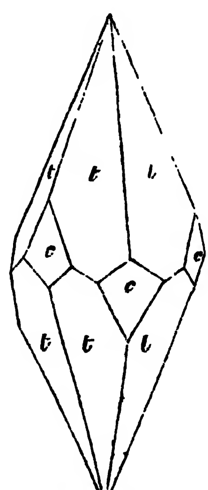


Fig. 293.

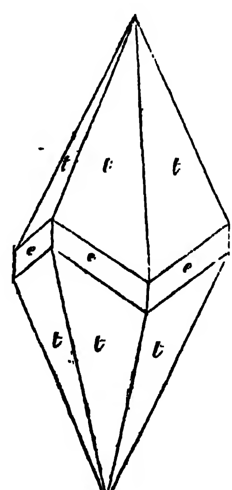


Fig. 294.

Fig. 293. Combination of a positive scalenohedron with the hexagonal prism of the second order. *t*, faces of scalenohedron. *c*, faces of prism.

Fig. 294. Combination of a positive scalenohedron with the hexagonal prism of the first order. *t*, faces of scalenohedron. *e*, faces of prism.

Fig. 295. Combination of hexagonal prism of the second order with positive rhomboid. *c*, faces of prism. R, faces of rhomboid.

Fig. 296. Combination of hexagonal prism of the first order with a positive rhomboid. *e*, faces of prism. R, faces of rhomboid.

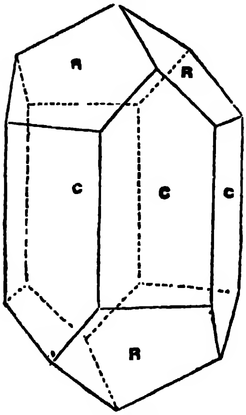


Fig. 295.

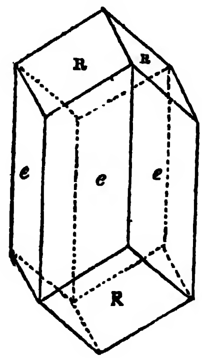


Fig. 296.

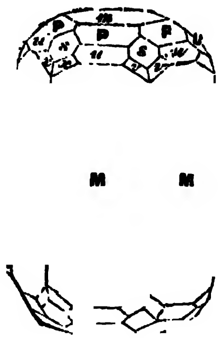


Fig. 297.

Fig. 297. Complex combination of forms in a crystal of Beryl.

m, face of basal pinacoid, 0 P Naumann, 1 1 1 Miller, a^1 Brooke and Levy.

P, faces of the double six-faced pyramid P Naumann; or faces of the rhomboid R Naumann, 1 0 0 Miller, P Brooke and Levy, and the rhomboid — R Naumann, $\bar{1}$ 2 2 Miller, $e^{\frac{1}{2}}$ Brooke and Levy.

u, faces of the double six-faced pyramid 2 P Naumann; or faces of the rhomboid 2 R Naumann, 5 $\bar{1}$ $\bar{1}$ Miller, e^5 Brooke and Levy, and of the rhomboid — 2 R Naumann, 1 1 $\bar{1}$ Miller, e^1 Brooke and Levy.

s, faces of the double six-faced pyramid 2 P 2 Naumann, 1 4 2 Miller, d^1 $d^{\frac{1}{4}}$ $b^{\frac{1}{2}}$ Brooke and Levy.

v, faces of the scalenohedron R^3 Naumann, 2 0 $\bar{1}$ Miller, d^2 Brooke and Levy.

x, faces of the scalenohedron — R^3 Naumann, $\bar{4}$ 2 5 Miller, $d^{\frac{1}{2}}$ $d^{\frac{1}{5}}$ $b^{\frac{1}{4}}$ Brooke and Levy.

x and *v*, together, giving the faces of the double twelve-faced pyramid 3 P $\frac{3}{2}$ Naumann.

M, faces of the hexagonal prism ∞ P Naumann, 2 $\bar{1}$ $\bar{1}$ Miller, e^2 Brooke and Levy.

Fig. 298. Complex combination of forms in a crystal of Apatite.

P, face of basal pinacoid, 0 P Naumann, 1 1 1 Miller, a^1 Brooke and Levy.

M, faces of the hexagonal prisms, ∞ P Naumann, 2 $\bar{1}$ $\bar{1}$ Miller, e^2 Brooke and Levy.

e, faces of the hexagonal prism, ∞ P 2 Naumann, 0 1 $\bar{1}$ Miller, d^1 Brooke and Levy.

a, faces of the pyramid, P 2 Naumann, 5 2 $\bar{1}$ Miller, $d^{\frac{1}{5}}$ $d^{\frac{1}{2}}$ b^1 Brooke and Levy.

s, faces of the pyramid, 2 P 2 Naumann, 1 4 $\bar{2}$ Miller, d^1 $d^{\frac{1}{4}}$ $b^{\frac{1}{2}}$ Brooke and Levy.

d, faces of the pyramid, 4 P 2 Naumann, 1 7 $\bar{5}$ Miller, d^1 $d^{\frac{1}{7}}$ $b^{\frac{1}{5}}$ Brooke and Levy.

x, faces of the pyramid, P Naumann; or of the rhomboids, R Naumann, 1 0 0 Miller, P Brooke and Levy; and — R Naumann, $\bar{1}$ 2 2 Miller, $e^{\frac{1}{2}}$ Brooke and Levy.

z, faces of the pyramid, 2 P Naumann; or of the rhomboids, 2 R Naumann, $5\ \bar{1}\ 1$ Miller, e^5 Brooke and Levy; and of — 2 R Naumann, $\bar{1}\ 1\ 1$ Miller, e^1 Brooke and Levy.

r, faces of the pyramid, $\frac{1}{2}$ P Naumann; or of the rhomboids, $\frac{1}{2}$ R Naumann, 4 1 1 Miller, a^4 Brooke and Levy; and of — $\frac{1}{2}$ R Naumann, 0 1 1 Miller, and b^1 Brooke and Levy.

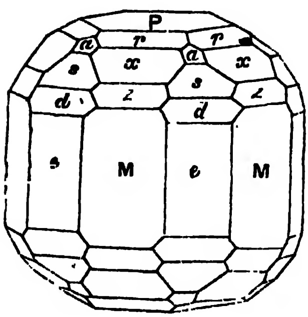


Fig. 298.

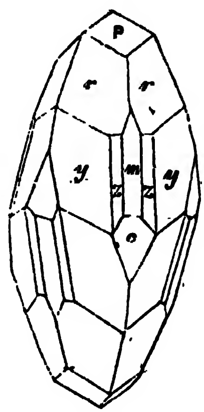


Fig. 299.

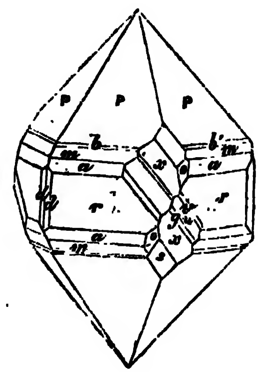


Fig. 300.

Fig. 299. Complex combination of forms in a crystal of calcareous spar.

P, faces of the rhomboid, R Naumann, 1 0 0 Miller, P Brooke and Levy.

m, faces of the rhomboid, 4 R Naumann, $3\ \bar{1}\ \bar{1}$ Miller, e^3 Brooke and Levy.

y, faces of the scalenohedron, R^5 Naumann, $3\ 0\ \bar{2}$ Miller, $d^{\frac{3}{2}}$ Brooke and Levy.

r, faces of the scalenohedron, R^3 Naumann, $2\ 0\ \bar{1}$ Miller, d^2 Brooke and Levy.

z, faces of the scalenohedron, $\frac{8}{3}$ R^3 Naumann, $15\ \bar{1}\ \bar{9}$ Miller, $d^1\ d^{\frac{1}{5}}\ b^{\frac{1}{15}}$ Brooke and Levy.

c, faces of the hexagonal prism, ∞ P Naumann, $2\ \bar{1}\ 1$ Miller; e^2 Brooke and Levy.

Fig. 300. Complex combination of forms in a crystal of quartz.

P, faces of the pyramid, P Naumann; or of the rhomboids, R Naumann, 1 0 0 Miller, P Brooke and Levy; and — R Naumann, $\bar{1}\ 2\ 2$ Miller, $e^{\frac{1}{2}}$ Brooke and Levy.

b, faces of the pyramid, $\frac{4}{3}$ P Naumann; or of the rhomboids, $\frac{4}{3}$ R Naumann, $13\ \bar{2}\ \bar{2}$ Miller, $e^{\frac{13}{2}}$ Brooke and Levy; and — $\frac{4}{3}$ R Naumann, $7\ \bar{8}\ \bar{8}$ Miller, $e^{\frac{7}{8}}$ Brooke and Levy.

m faces of the pyramid, 3 P Naumann; or of the rhomboids, 3 R Naumann, $7\ 2\ \bar{2}$ Miller, $e^{\frac{7}{2}}$ Brooke and Levy; and — 3 R Naumann, $\bar{5}\ 4\ 4$ Miller, $e^{\frac{5}{4}}$ Brooke and Levy.

a faces of the pyramid, 4 P Naumann; or of the rhomboids, 4 R Naumann, $3\ \bar{1}\ \bar{1}$ Miller, e^3 Brooke and Levy, and — 4 R Naumann, $\bar{7}\ 5\ 5$ Miller, $e^{\frac{7}{5}}$ Brooke and Levy.

s faces of a double three-faced pyramid derived from the double six-faced pyramid, 2 P 2 Naumann, $1\ 4\ \bar{2}$ Miller, $d^1\ d^{\frac{1}{4}}\ b^{\frac{1}{2}}$ Brooke and Levy.

o faces of the double three-faced trapezohedron derived from the scalenohedron $- R^3$ Naumann, $\bar{4}\,2\,5$ Miller, $d^{\frac{1}{2}}\, d^{\frac{1}{5}}\, b^{\frac{1}{4}}$ Brooke and Levy.

x faces of the double three-faced trapezohedron derived from the scalenohedron $2\,R^3$ Naumann, $8\,\bar{1}\,\bar{4}$ Miller, $d^1\, d^{\frac{1}{4}}\, b^{\frac{1}{5}}$ Brooke and Levy.

g faces of the trapezohedron $3\,R^{\frac{5}{3}}$ Naumann, $10\,\bar{2}\,\bar{5}$ Miller, $d^{\frac{1}{2}}\, d^{\frac{1}{5}}\, b^{\frac{1}{10}}$ Brooke and Levy.

u faces of the trapezohedron $4\,R^{\frac{3}{2}}$ Naumann, $4\,\bar{1}\,\bar{2}$ Miller, $d^1\, d^{\frac{1}{2}}\, b^{\frac{1}{4}}$ Brooke and Levy.

v faces of the trapezohedron $6\,R^{\frac{4}{3}}$ Naumann, $16\,\bar{5}\,\bar{8}$ Miller, $d^{\frac{1}{5}}\, d^{\frac{1}{8}}\, b^{\frac{1}{16}}$ Brooke and Levy.

r faces of the hexagonal prism ∞ P Naumann, $2\,\bar{1}\,\bar{1}$ Miller, e^2 Brooke and Levy.

d faces of the dihexagonal prism ∞ P $\frac{3}{2}$ Naumann, $\bar{5}\,\bar{1}\,4$ Miller, $d^1\, d^{\frac{1}{4}}\, b^{\frac{1}{5}}$ Brooke and Levy.

FOURTH SYSTEM—PRISMATIC OR RHOMBIC.

This system is called the *Prismatic* or *Rhombic*, as its forms may be derived either from the prism, or octahedron on a rhombic base. It has also been called the *orthotype* and the *one and one axial* system.

The *holohedral forms* of this system are *a right prism on a rectangular base*, three kinds or orders of *right prisms on a rhombic base*, and the *double four-faced pyramid on a rhombic base*. The *hemihedral form* is the *rhombic sphenoid* derived from the double four-faced pyramid.

Alphabetical list of Minerals belonging to the Prismatic System, with the Angular Elements from which their Typical Forms and Axes may be derived.

Aeschynite	26° 20′;	33° 46′	Eudnophite	Unknown.	
Alstonite	30° 34′;	36° 27′	Fayalite	42° 40′;	49° 11′
Amblygonite	Unknown.		Fluellite	37° 35′;	61° 58′
Andalusite	44° 38′;	35° 5′	Gadolonite	30° 15′;	50° 30′
Anglesite (sulphate of lead)	38° 11′;	52° 16′	Glaserite (sulphate of potash)	29° 48′;	36° 44′
Antimonsilber	30° 0′;	33° 53′	Glaucodote	Unknown.	
Antimonite	44° 37′;	45° 36′	Goslarite (sulphate of zinc)	44° 39′;	20° 58′
Aragonite (carbonate of lime)	31° 55′;	35° 47′	Göthite	42° 34′;	31° 15′
Baryte (sulphate of barytes)	39° 10′;	52° 42′	Haidingerite	40° 0′;	26° 31′
Bismuthine	44° 30′;	Unkn.	Harmotome	44° 7′;	34° 47′
Bournonite	43° 10′;	41° 53′	Herderite	32° 3′;	23° 1′
Brochantite	37° 55′;	14° 4′	Ilvaite	34° 24′;	24° 31′
Brookite	40° 5′;	43° 22′	Jamesonite	39° 20′:	Unkn.
Caledonite (cupreous sulphato-carbonate of lead)	42° 30′;	54° 31′	Karstenite (anhydrous sulphate of lime)	41° 42′;	44° 25′
Celestine (sulphate of strontian)	37° 59′;	52° 4′	Leadhillite (sulphato-carbonate of lead)	29° 50′;	51° 37′
Cerussite (carbonate of lead)	31° 23′;	35° 52′	Libethenite (phosphate of copper)	43° 50′;	35° 4′
Childrenite	34° 3′;	32° 44′	Liroconite (octahedral arseniate of copper)	30° 20′;	38° 20′
Chloanthite	Unknown.		Loganite	Unknown.	
Chrysoberyl	25° 11′;	30° 7′	Lölingite	28° 47′;	41° 10′
Comptonite	Unknown.		Manganite	40° 10′;	28° 35′
Cordierite	30° 25′;	29° 11′	Marcasite	36° 57′;	49° 50′
Cotunnite	40° 7′;	26° 38′	Mascagnine (sulph. of ammonia)	29° 26′;	36° 10′
Cryolite	Unknown.		Mendipite	Unknown.	
Datholite	38° 22′;	26° 34′	Mengite	21° 50′;	19° 14′
Diaspore	43° 4′;	30° 39′	Mesotype	44° 30′;	19° 24′
Dufrenite (phosphate of iron)	Unknown.		Mispickel	34° 3′;	49° 56′
Epistilbite	22° 25′;	16° 10′	Monticellite	41° 5′;	48° 40′
Epsomite (sulphate of magnesia)	44° 43′;	29° 43′			
Euchroite	31° 20′;	46° 4′			

Niobite . .	39° 40′; 41° 16′	Staurolite . .	25° 20′; 34° 26
Nitre (nitrate of potash)	30° 35′; 35° 1′	Stephanite . .	32° 10′; 34° 26′
Olivenite (right prismatic arseniate of copper)	43° 45′; [illegible] 35′	Sternbergite . .	30° 15′; 40° 0′
Olivine .	42° 58′; 49° 33′	Stilbite . . .	42° 52′; 37° 4′
Orpiment	30° 5′; 33° 0′	Strontianite (carbonate of strontian) . .	31° 21′; 35° 54′
Patrinite .	Unknown.	Stromeyerite . .	30° 12′; 44° 8′
Phillipsite	44° 24′; 34° 59′	Struvite . . .	28° 35′; 31° 34′
Picrosmine	26° 34′; 16° 48′	Sulphur . . .	39° 1′; 62° 12′
Polianite .	43° 34′; 31° 0′	Sylvanite . . .	34° 36′; 31° 26′
Polyhalite	Unknown.	Tantalite . . .	39° 14′; 33° 6′
Polykrase	20° 0′; 18° 53′	Thenardite (sulphate of soda)	25° 19′; 28° 50′
Polymignyte	35° 7′; 31° 24′	Thermonatrite (prismatic carbonate of soda) .	20° 1′; 48° 5′
Porzellanspath	Unknown.	Topaz . . .	27° 50′; 43° 31′
Prehnite .	40° 2′; 40° 9′	Triplite (phosphate of manganese) . .	Unknown.
Pyrolusite	43° 10′; 20° 0′	Tyrolite . . .	Unknown.
Pyrophyllite	Unknown.	Valentinite . .	21° 31′; 54° 44′
Redruthite	30° 12′; 44° 8′	Wavellite . .	26° 47′; 20° 34′
Remolinite (muriate of copper)	33° 50′; 37° 10′	Witherite (carbonate of barytes)	30° 45′; 36° 33′
Roselite .	23° 36′; 31° 51′	Wölchite . . .	Unknown.
Samarskite	39° 40′; 41° 16′	Wolfram (tungstate of iron) .	39° 7′; 40° 46′
Schulzite	Unknown.	Wolfsbergite . .	22° 24′; Unkn.
Scorodite (martial arseniate of copper) . .	40° 59′; 43° 39′	Zinckenite . .	29° 40′; 8° 30′
Smithsonite (siliceous oxide of zinc) . .	38° 3′; 25° 40′	Zwiselite . . .	Unknown.

The Right Rectangular Prism.—The right rectangular prism, or the right prism on a rectangular base, is a solid form bounded by six faces; these faces are all rectangular parallelograms, and equal to each other in pairs; thus (Fig. 301), the face $B_1\ B_5\ B_8\ B_4$ is equal to the face $B_2\ B_6\ B_7\ B_3$, $B_1\ B_2\ B_6\ B_5$ to $B_4\ B_3\ B_7\ B_8$, and $B_1\ B_2\ B_3\ B_4$ to $B_5\ B_6\ B_7\ B_8$.

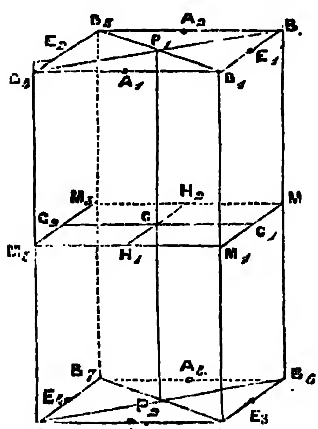


Fig. 301.

Modern writers consider this prism as a combination of three open forms, each form consisting of a pair of parallel faces; the bases of the prism are then called the *basal pinacoids*, the wider sides *macro-pinacoids*, and the narrower *brachy-pinacoids*.

Axes of the Right Rectangular Prism and the Prismatic System.—Join $B_1\ B_3$ and $B_2\ B_4$, cutting each other in P_1, also $B_6\ B_8$ and $B_5\ B_7$, cutting each other in P_2. Bisect $B_1\ B_5$, $B_2\ B_6$, $B_3\ B_7$, and $B_4\ B_8$ in the points M_1, M_2, M_3 and M_4. Join $M_1\ M_2$, $M_2\ M_3$, $M_3\ M_4$, and $M_4\ M_1$. Bisect $M_1\ M_2$ and $M_3\ M_4$ in the points G_1 and G_2, and $M_1\ M_4$ and $M_2\ M_3$ in H_1 and H_2. Join $P_1\ P_2$, $H_1\ H_2$, and $G_1\ G_2$, cutting each other in C. The three lines $P_1\ P_2$, $H_1\ H_2$, and $G_1\ G_2$, which are at right angles to each other, are the *axes* of the *rectangular prism*, and also of the *prismatic system*. $P_1\ P_2$ is called the principal axis, and $H_1\ H_2$ and $G_1\ G_2$ the secondary axes.

Parameters.—The semi-axes CP_1, CG_1, and CH_1, are the *parameters* of the prismatic system; the length of CG_1 is perfectly arbitrary, but its length once chosen, the lengths of CP_1 and CH_1 depend upon the angular elements already given for each mineral belonging to the system.

To determine CP_1 and CH_1 draw CG (Fig. 302) of any convenient length, as the *arbitrary unit* of the system of axes.

Draw CP perpendicular to GC. Let α be the angle given in the first, and β the angle given in the second column of the angular elements.

Draw HG making the angle α, and PG making the angle β, with GC.

Let H and P be the points where GH and GP meet the perpendicular CP.

For Aeschynite, the angle CGH is 26° 20′, and the angle CGP 33° 46′; for Alstonite, the angle CGH is 30° 34′, and the angle CGP 36° 28′; and so on for the other substances belonging to the prismatic system.

The lines CG, CH, and CP, thus determined, are the parameters of the prismatic system; it appears, therefore, that the *axes* of this system are *rectangular*, and its three *parameters* all *unequal* to each other.

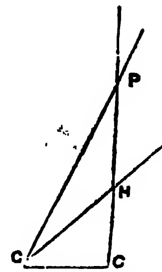


Fig. 302.

To draw the Right Rectangular Prism.—Draw B_8 B_5 (Fig. 301) equal to twice GC (Fig. 302). Through B_8 draw B_8 B_7, making an angle of about 30°, with B_8 B_5.

Make B_8 B_7 equal to CH (Fig. 302). Through B_5 draw B_5 B_6 equal and parallel to B_8 B_7; join B_7 B_6.

Through B_8 draw B_8 B_4 perpendicular to B_8 B_5 and equal to twice CP (Fig. 302).

Through B_5, B_6 and B_7 draw B_5 B_1, B_6 B_2, and B_7 B_3 parallel and equal to B_8 B_4.

Join the points B_1 B_2 B_3 and B_4, and the prism will be represented in perspective.

Symbols.—Each face of the rectangular prism cuts one of the three axes at a distance from C (Fig. 301), the centre of the axes, equal to the length of one of the parameters, and is parallel to the other two axes.

The two *basal pinacoids*, or extremities of the prism B_1 B_2 B_3 B_4 and B_5 B_6 B_7 B_8, cut the axis P_1 P_2 in the points P_1 and P_2, and are parallel to the axes G_1 G_2 and H_1 H_2. The symbol which represents the relation of these faces of the prism to the axes is ∞ ∞ 1.

Naumann's symbol is 0P; Miller's 0 0 1; Brooke and Levy's modification of Haüy is P, when they regard the right rhombic prism as the primitive form of the crystal.

The two *macro-pinacoids*, or broader sides of the prism, B_1 B_4 B_8 B_5 and B_2 B_3 B_7 B_6 cut the axis H_1 H_2 in the points H_1 and H_2, and are parallel to the axes P_1 P_2 and G_1 G_2. The symbol representing this relation is ∞ 1 ∞.

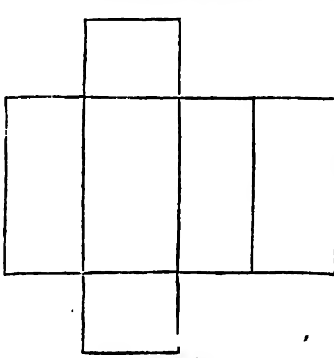


Fig. 303.

Naumann's symbol is $\infty \bar{P} \infty$, Miller's 0 1 0, Brooke and Levy's H.

The two *brachy-pinacoids*, or narrower sides of the prism, B_1 B_2 B_6 B_5 and B_4 B_3 B_7 B_8, cut the axis G_1 G_2 in the points G_1 and G_2, and are parallel to the axes H_1 H_2 and P_1 P_2. The symbol representing this relation is 1 ∞ ∞. Naumann's symbol is $\infty \breve{P} \infty$, Miller's 1 0 0, Brooke and Levy's G.

To describe a Net for the Right Rectangular Prism. — Take two parallelograms equal to B_1 B_4 B_8 B_5 (Fig. 301), to represent the *macro-pinacoids*, two others equal in length to these, but with a breadth equal to twice CH (Fig. 302) for the *brachy-pinacoids*, and two

parallelograms each twice GC (Fig. 302) in breadth, and twice CH in length for the *basal-pinacoids*; arrange these six rectangular parallelograms as in Fig. 303, and the required net will be constructed.

Crystals of the following minerals have Faces parallel to the Basal Pinacoids $\infty\ \infty\ 1$.

0 P Naumann, 0 0 1 Miller, P Brooke and Levy.

Aeschynite	Comptonite	Ilvaite	Olivine	Strontianite
Andalusite	Cordierite	Jamesonite	Polyhalite	Stromeyerite
Anglesite	Cotunnite	Karstenite	Polymignite	Sulphur
Antimonsilber	Cryolite	Leadhillite	Prehnite	Sylvanite
Antimonite	Datholite	Loganite	Pyrolusite	Tantalite
Aragonite	Diaspore	Lölingite	Redruthite	Thenardite
Baryte	Euchroite	Manganite	Roselite	Thermonatrite
Bismuthine	Eudnophite	Marcasite	Scorodite	Topaz
Bournonite	Fayalite	Mascagnine	Smithsonite	Tyrolite
Brookite	Fluellite	Mendipite	Staurolite	Witherite
Caledonite	Gadolonite	Mispickel	Stephanite	Wölchite
Celestine	Glaserite	Niobite	Sternbergite	Wolfram
Cerussite	Herderite	Nitre	Stilbite	Wolfsbergite
Chrysoberyl				

The following present Cleavages parallel to this form.

Anglesite	Chrysoberyl	Jamesonite	Mascagnine	*Sternbergite*
Antimonsilber	Comptonite	*Karstenite*	Mispickel	Tantalite
Antimonite	*Cryolite*	*Leadhillite*	Niobite	*Thenardite*
Baryte	*Eudnophite*	*Loganite*	*Prehnite*	*Topaz*
Bournonite	*Fayalite*	Lölingite	*Roselite*	*Tyrolite*
Caledonite	Glaserite	Manganite	Smithsonite	Wolfsbergite
Celestine				

Minerals whose Crystals present Faces parallel to the Macro-pinacoids $\infty\ 1\ \infty$.

$\infty \bar{P} \infty$ Naumann, 0 1 0 Miller, H Brooke and Levy.

Aeschynite	Comptonite	Haidingerite	Nitre	Remolinite
Andalusite	Cordierite	Harmotome	Olivenite	Schulzite
Anglesite	Cotunnite	Herderite	Olivine	Scorodite
Antimonsilber	Cryolite	Ilvaite	Orpiment	Smithsonite
Antimonite	Datholite	Jamesonite	Phillipsite	Stephanite
Aragonite	Epsomite	Karstenite	Picrosmine	Stilbite
Baryte	Eudnophite	Libethenite	Polianite	Struvite
Bismuthine	Fayalite	Loganite	Polykrase	Sulphur
Bournonite	Gadolonite	Manganite	Polymignite	Sylvanite
Brookite	Glaserite	Mascagnine	Prehnite	Tantalite
Celestine	Goslarite	Mendipite	Pyrolusite	Wölchite
Cerussite	Göthite	Niobite	Redruthite	Wolfram
Chrysoberyl				

Cleavages parallel to this form occur in the following minerals.

Aeschynite	Chrysoberyl	*Jamesonite*	*Niobite*	*Pyrolusite*
Andalusite	Comptonite	*Karstenite*	Olivine	Scorodite
Antimonite	Cryolyte	Loganite	Orpiment	Stilbite
Baryte	Eudnophite	Manganite	Phillipsite	*Struvite*
Bournonite	Fayalite	Mascagnine	Picrosmine	Tantalite
Celestine	Harmotome	Mendipite	Polymignite	*Wolfram*

Minerals whose Crystals present Faces parallel to the Brachy-pinacoids $1\ \infty\ \infty$

$\infty \breve{P} \infty$ Naumann, 1 0 0 Miller, G Brooke and Levy.

Aeschynite	Bismuthine	Chrysoberyl	Epsomite	Harmotome
Alstonite	Bournonite	Comptonite	Euchroite	Herderite
Andalusite	Brochantite	Cordierite	Eudnophite	Ilvaite
Anglesite	Brookite	Cotunnite	Fayalite	Jamesonite
Antimonsilber	Caledonite	Cryolite	Glaserite	Karstenite
Antimonite	Celestine	Datholite	Goslarite	Leadhillite
Aragonite	Cerussite	Diaspore	Göthite	Libethenite
Baryte	Childrenite	Epistilbite	Haidingerite	Loganite

Manganite	**Olivenite**	**Prehnite**	**Sternbergite**	**Topaz**
Mascagnine	**Olivine**	**Pyrolusite**	**Stilbite**	**Tyrolite**
Mendipite	**Orpiment**	**Redruthite**	**Strontianite**	**Valentinite**
Mengite	**Phillipsite**	**Remolinite**	**Stromeyerite**	**Wavellite**
Mesotype	**Picrosmine**	**Roselite**	**Struvite**	**Witherite**
Mispickel	**Polianite**	**Scorodite**	**Sylvanite**	**Wölchite**
Montieellite	**Polyhalite**	**Smithsonite**	**Tantalite**	**Wolfram**
Niobite	**Polykrase**	**Staurolite**	**Thenardite**	**Wolfsbergite**
Nitre	**Polymignite**	**Stephanite**	**Thermonatrite**	**Zinckenite**

Cleavages parallel to this form occur in the following minerals.

Alstonite	**Childrenite**	**Glaserite**	**Nitre**	**Stephanite**
Andalusite	**Chrysoberyl**	***Göthite***	***Olivine***	***Stilbite***
Anglesite	***Comptonite***	***Haidingerite***	***Orpiment***	**Strontianite**
Antimonite	**Cordierite**	***Harmotome***	***Phillipsite***	**Tantalite**
Aragonite	**Cryolite**	**Jamesonite**	***Picrosmine***	**Thermonatrite**
Baryte	**Datholite**	***Karstenite***	***Polianite***	***Wavellite***
Bournonite	***Diaspore***	**Leadhillite**	**Polymignite**	**Witherite**
Brochantite	***Epistilbite***	***Manganite***	***Pyrolusite***	**Wölchite**
Brookite	***Epsomite***	***Mascagnine***	***Remolinite***	***Wolfram***
Caledonite	**Eudnophite**	**Mendipite**	**Scorodite**	***Wolfsbergite***
Celestine	**Fayalite**	***Niobite***	***Staurolite***	

Right Rhombic Prism of the First Order.—The right rhombic prism of the first order, or the *rectangular prism on a rhombic base*, is a solid bounded by six faces, four of which are rectangular parallelograms, such as $A_1\ E_2\ E_3\ A_2$ (Fig. 304); the other two are rhombs. When this prism is considered as an open form, the four rectangular faces only are taken as its faces, the two rhombic faces which inclose it being then regarded as the *basal pinacoids*.

To draw the Rhombic Prism of the First Order.—Bisect

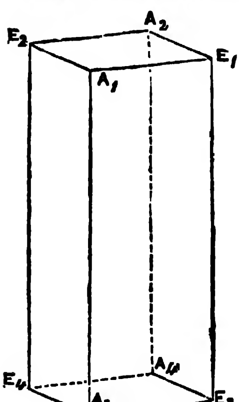


Fig. 304.

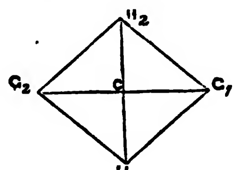


Fig. 305.

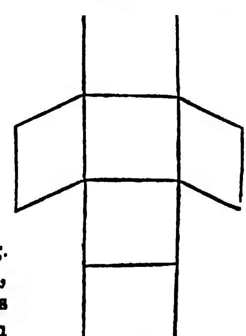


Fig. 306.

the edges $B_1\ B_4$, $B_2\ B_3$, $B_8\ B_5$, and $B_6\ B_7$ of the prism (Fig. 301), in the points A_1, A_2, A_3, and A_4; also $B_1\ B_2$, $B_4\ B_3$, $B_5\ B_6$, and $B_8\ B_7$, in E_1, E_2, E_3, and E_4. Prick off the points A_1, A_2, A_3, A_4, E_1, E_2, E_3 and E_4, and join these points, as in Fig. 304, and the prism will be represented.

Symbols.—Each face of this prism, considered as an open form, cuts two of the axes $G_1\ G_2$ (Fig. 301) and $H_1\ H_2$, at the extremities of their parameters, and is parallel to the third axis $P_1\ P_2$; the symbol representing this property is $1\ 1\ \infty$; Naumann's is ∞P, Miller's $1\ 1\ \infty$, and Brooke and Levy's M.

To Describe a Net for the Rhombic Prism.—Draw two lines, $G_1\ G_2$ and $H_1\ H_2$ (Fig. 305), cutting each other at right angles in the point C. Make CG_1 and CG_2 each equal CG (Fig. 302), and CH_1, CH_2 equal to CH (Fig. 302).

Join H_1, G_1, H_2 and G_2, as in Fig. 305. Draw two such rhombs, also four equal

rectangular parallelograms, their breadths being equal to $H_1\,G_1$, and of any convenient length. Arrange these figures as in Fig. 306, and the net will be described.

Sphere of Projection for the Prismatic System.—To draw a map of the sphere of projection of the prismatic system, with P_1 (Fig. 307) as a centre, and any convenient radius $P_1\,G_1$ describe the circle $G_1\,H_1\,G_2$. Let $G_1\,G_2$, and $H_1\,H_2$, be any two diameters drawn perpendicular to each other. Then P_1, representing the north pole of the sphere of projection, is the pole of the upper basal pinacoid $\infty\ \infty\ 1$, or 0 P, Naumann; G_1 and G_2 are the poles of the brachy-pinacoids $1\ \infty\infty$, or $\infty\ \breve{P}\ \infty$, Naumann; and H_1 and H_2 are the poles of the macro-pinacoid $\infty\ 1\ \infty$, or $\infty\bar{P}\infty$, Naumann.

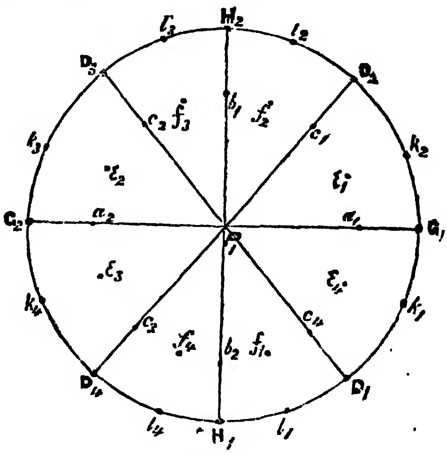


Fig. 307.

Faces parallel to the Rhombic Prism of the First Order, 1 1 ∞; ∞ P *Naumann;* 1 1 0 *Miller;* M *Brooke and Levy; occur in the following minerals: the angles are the longitude of their poles.*

Aeschynite	40′	Göthite	47° 26′	Polyhalite	57° 30′
Alstonite	26′	Haidingerite	50° 0′	Polykrase	70° 0′
Andalusite	22′	Harmotome	45° 53′	Polymignite	54° 53′
Anglesite	49′	Herderite	57° 57′	Prehnite	49° 58′
Antimonsilbe	60° 0′	Ilvaite	55° 36′	Pyrolusite	46° 50′
Antimonite	45° 23′	Jamesonite	50° 40′	Redruthite	59° 48′
Aragonite	58°	Karstenite	48° 18′	Remolinite	56° 10′
Baryte	50° 50′	Leadhillite	60° 10′	Roselite	66° 24′
Bismuthine	45°	Libethenite	46° 10′	Scorodite	49° 1′
Bournonite	46°	Liroconite	59° 40′	Smithsonite	51° 57′
Brochantite		Loganite	Unkn.	Staurolite	64° 40′
Brookite	55′	Lolingite	61° 13′	Stephanite	57° 50′
Caledonite	30′	Manganite	49° 50′	Sternbergite	59° 45′
Celestine	52° 1′	Marcasite	53° 3′	Stilbite	47° 8′
Cerussite	58° 37′	Mascagnine	60° 34′	Strontianite	58° 40′
Chloanthite	62° 0′	Mendipite	51° 18′	Struvite	61° 25′
Chrysoberyl	64° 49′	Mengite	68° 10′	Sulphur	50° 59′
Comptonite	45° 20′	Mesotype	45° 30′	Sylvanite	55° 24′
Cordierite	59° 35′	Mispickel	55° 36′	Thenardite	64° 41′
Cotunnite	49° 53′	Monticellite	48° 55′	Topaz	62° 10′
Datholite	51° 38′	Niobite	50° 20′	Tyrolite	Unkn.
Epistilbite	67° 35′	Nitre	59° 25′	Valentinite	68° 29′
Epsomite	45° 17′	Olivenite	46° 15′	Wavellite	63° 13′
Euchroite	58° 40′	Olivine	47° 1′	Witherite	59° 15′
Eudnophite	60° 0′	Orpiment	58° 55′	Wölchite	Unkn.
Fayalite	47° 20′	Phillipsite	45° 36′	Wolfram	50° 53′
Gadolorite	59° 45′	Picrosmine	63° 26′	Wolfsbergite	67° 36′
Glaserite	60° 12′	Polianite	46° 26′	Zinckenite	60° 20′
Goslarite	45° 21′				

The following minerals present Cleavages parallel to this form.

Alstonite	Brochantite	Jamesonite	Mispickel	*Strontianite*
Andalusite	Caledonite	Leadhillite	Nitre	Sulphur
Anglesite	Celestine	Liroconite	Olivenite	Thenardite
Antimonsilber	Cerussite	*Loganite*	Prehnite	Topaz
Antimonite	Datholite	*Manganite*	*Pyrolusite*	*Valentinite*
Aragonite	Epsomite	Marcasite	Redruthite	*Wavellite*
Baryte	Euchroite	*Mendipite*	*Smithsonite*	*Witherite*
Bismuthine	Glaserite	*Mesotype*	Staurolite	

Position of the Poles of the Right Rhombic Prism on the Sphere of Projection.—The poles of this prism all lie in the equator, if θ be the angle of longitude for each substance given above; and if (in Fig. 307) $G_1 D_1$, $G_1 D_2$, $G_2 D_3$, and $G_2 D_4$, be each taken equal to θ, D_1, D_2, D_3 and D_4, will represent the four poles of the prism.

Right Rhombic Prisms derived from the Right Rhombic Prism of the First Order by increasing the greater Axis $G_1 G_2$.—These prisms will be similar, in all respects, to the prism of the first order, from which they are derived, except that CG_1 and CG_2 (Fig. 301) must be taken n times greater than GC (Fig. 302). Making this alteration, the points A_1, A_2, A_3, A_4, E_1, E_2, E_3, and E_4, will give the angular points of the derived prism. Their symbols will be $n\,1\,\infty$, $\infty\,\bar{P}\,n$ Naumann, $h\,k\,o$ Miller, $H^{\frac{n+1}{n-1}}$ Brooke and Levy.

Faces parallel to the following forms of these Prisms have been observed in nature; the angle is that of their longitude.

The form $\frac{4}{3}\,1\,\infty$; $\infty\,\bar{P}\,\frac{4}{3}$ Naumann; 3 4 0 Miller; H^7 Brooke and Levy.

Fayalite . .	55° 20′	Manganite . .	57° 40′

The form $\frac{3}{2}\,1\,\infty$; $\infty\,\bar{P}\,\frac{3}{2}$ Naumann; 2 3 0 Miller; H^5 Brooke and Levy.

Baryte . . .	61° 30′	Bournonite . .	57° 59′

The form $\frac{5}{3}\,1\,\infty$; $\infty\,\bar{P}\,\frac{5}{3}$ Naumann; 3 5 0 Miller; H^4 Brooke and Levy.

Cerussite .	69° 36′

The form $2\,1\,\infty$; $\infty\,\bar{P}\,2$ Naumann; 1 2 0 Miller; H^3 Brooke and Levy.

Andalusite . .	63° 44′	Fayalite . .	65° 12′	Monticellite	66° 27′
Antimonite . .	63° 44′	Göthite . . .	65° 20′	Niobite .	67° 29′
Baryte . . .	67° 50′	Ilvaite . . .	71° 6′	Olivine .	65° 1′
Bournonite . .	64° 52′	Libethenite . .	61° 22′	Struvite	42° 32′
Brookite . .	67° 11′	Manganite . .	67° 7′	Wolfram	67° 52′
Diaspore . .	64° 57′				

Diaspore has an imperfect cleavage parallel to the above form.

The form $4\,1\,\infty$; $\infty\,\bar{P}\,4$ Naumann; 1 4 0 Miller; $H^{\frac{5}{3}}$ Brooke and Levy.

Brookite . .	78° 7′	Manganite . .	78° 5′

The form $\frac{11}{2}\,1\,\infty$; $\infty\,\bar{P}\,\frac{11}{2}$ Naumann; 2 11 0 Miller; $H^{\frac{13}{9}}$ Brooke and Levy.

Brookite . .	81° 18′

The form $\frac{23}{4}\,1\,\infty$; $\infty\,\bar{P}\,\frac{23}{4}$ Naumann; 4 23 0 Miller; $H^{\frac{27}{19}}$ Brooke and Levy.

Brookite . .	81° 40′

Poles of these derived Rhombic Prisms of the First Order on the Sphere of Projection, &c.—If $G_1\,l_1$, $G_1\,l_2$, $G_2\,l_3$, and $G_2\,l_4$, on the equator of the sphere of projection, be each taken equal to the angle of longitude given above, in Fig. 307, l_1, l_2, l_3, and l_4, will be the four poles of the prism. If a be the angular element given in the first column, θ the longitude of the prism $n\,1\,\infty$, for any particular substance, then

$$\tan\theta = n\cot a.$$

2θ will be the inclination of the faces of the prism over the edges $E_1 E_3$ or $E_2 E_4$ (Fig. 304); $180° - 2\theta$, their inclination over the edges $A_1 A_3$ and $A_2 A_4$.

Right Rhombic Prisms derived from the Right Rhombic Prism of the First Order, by increasing the Lesser Axis $H_1 H_2$.—These prisms are derived from the prism of the first order, by making CH_1 and CH_2 (Fig. 301) equal to n times CH (Fig. 301). With this alteration A_1, A_2, A_3, A_4, E_1, E_2, E_3 and E_4, will give the angular points of the new prism.

The symbol of these derived prisms will be $1\,n\,\infty$; $\infty\breve{P}\,n$ Naumann; $k\,h\,o$ Miller; $G^{\frac{n+1}{n-1}}$ Brooke and Levy.

Faces parallel to the following forms of these Prisms have been observed in nature; the angle is that of their longitude.

The form $1\,\frac{4}{3}\,\infty$; $\infty\breve{P}\,\frac{4}{3}$ Naumann; 4 3 0 Miller; G^7 Brooke and Levy.

Anglesite	43° 34′	Antimonite	37° 14′	Bournonite	38° 39′
		Wavellite	56° 3′		

The form $1\,\frac{3}{2}\,\infty$; $\infty\breve{P}\,\frac{3}{2}$ Naumann; 3 2 0 Miller; G^5 Brooke and Levy.

Diaspore	35° 30′	Manganite	38° 18′	Redruthite	48° 52′
Euchroite	47° 30′	Olivine	35° 35′	Topaz	51° 37′
Fayalite	35° 52′				

The form $1\,\frac{5}{2}\,\infty$; $\infty\breve{P}\,\frac{5}{2}$ Naumann; 5 2 0 Miller; $G^{\frac{7}{3}}$ Brooke and Levy.

Fayalite	23° 27′	Manganite	25° 21′

The form $1\,2\,\infty$; $\infty\breve{P}\,2$ Naumann; 2 1 0 Miller; G^3 Brooke and Levy.

Aeschynite	45° 17′	Diaspore	28° 9′	Remolinite	36° 43′
Anglesite	32° 27′	Epsomite	26° 49′	Schulzite	30° 8′
Antimonsilber	40° 54′	Euchroite	39° 24′	Scorodite	29° 55′
Baryte	31° 33′	Goslarite	26° 43′	Sulphur	31° 49′
Bournonite	28° 4′	Göthite	28° 34′	Sylvanite	35° 56′
Brochantite	32° 42′	Ilvaite	36° 8′	Thermonatrite	53° 55′
Celestine	32° 38′	Manganite	30° 38′	Topaz	43° 26′
Chrysoberyl	56° 47′	Olivine	28° 13′	Wolfram	31° 35′
Cotunnite	30° 41′	Orpiment	39° 40′	Wolfsbergite	50° 30′
Datholite	32° 17′	Polymignite	35° 25′		

The form $1\,\frac{9}{4}\,\infty$; $\infty\breve{P}\,\frac{9}{4}$ Naumann; 9 4 0 Miller; $G^{\frac{13}{5}}$ Brooke and Levy.

Tantalite	28° 33′

The form $1\,3\,\infty$; $\infty\breve{P}\,3$ Naumann; 3 1 0 Miller; G^2 Brooke and Levy.

Antimonsilber	30° 0′	Glaserite	30° 12′	Mengite	39° 46′
Bismuthine	18° 44′	Ilvaite	25° 57′	Niobite	21° 54′
Cerussite	28° 39′	Leadhillite	30° 10′	Smithsonite	25° 4′
Chrysoberyl	35° 21′	Manganite	21° 33′	Sylvanite	25° 47′
Cordierite	29° 35′	Mascagnine	30° 34′	Topaz	32° 16′
Datholite	22° 50′				

The form $1\,\frac{7}{2}\,\infty$; $\infty\breve{P}\,\frac{7}{2}$ Naumann; 7 2 0 Miller; $G^{\frac{9}{5}}$ Brooke and Levy.

Chrysoberyl	31° 17′

The form $1\,4\,\infty$; $\infty\breve{P}\,4$ Naumann; 4 1 0 Miller; $G^{\frac{5}{3}}$ Brooke and Levy.

Ilvaite	20° 3′	Polymignite	19° 35′	Topaz	25° 20′
Leadhillite	23° 33′	Remolinite	20° 28′		

The form $1\,5\,\infty$; $\infty\breve{P}\,5$ Naumann; 5 1 0 Miller; $G^{\frac{3}{2}}$ Brooke and Levy.

Antimonsilber	16° 6′	Antimonite	11° 27′	Smithsonite	14° 20′

Poles of these derived Rhombic Prisms of the First Order on the Sphere of Projection, &c. —Take $G_1\,K_1$, $G_1\,K_2$, $G_2\,K_3$ and $G_2\,K_4$ (Fig. 307) on the equator of the sphere of projection, each equal to the angle of longitude given above. $K_1\,K_2\,K_3$ and K_4 will be the four poles of the prism.

If α be the angular element given in the first column, θ the longitude of the prism, $1\,n\,\infty$ for any particular substance, then

$$\cot\theta = n\tan\alpha$$

2θ will be the inclination of the faces of the prism over the edges $A_1\,A_3$, $A_2\,A_4$ (Fig. 304); $180° - 2\theta$, their inclination over the edges $E_1\,E_3$ or $E_2\,E_4$.

Right Rhombic Prism of the Second Order.—The right rhombic prism of the second order is similar in form, but different in position, to that of the first order. The four faces (Fig. 308) which are rectangular parallelograms, cut the two axes P_1 P_2 and G_1 G_2 (Fig. 301) in the points P and G, and are parallel to the third axis H_1 H_2 (Fig. 301).

The rhombic planes A_1 M_1 A_3 M_4 and A_2 M_2 A_4 M_3 which inclose the prism are the macro-pinacoids.

To draw this prism, we have only to prick off the points A_1, A_2, A_3, A_4, E_1, E_2, E_3, and E_4 from the Fig. 301, and join them as in Fig. 308.

Symbols.—The symbol which represents the relation of this prism to the axes of the prismatic system is 1 ∞ 1; Naumann's $\breve{P}\infty$; Miller's 1 0 1; Brooke and Levy's $E^{\frac{1}{2}}$.

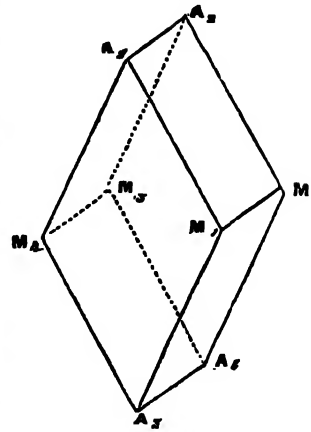


Fig. 308.

Faces parallel to the Prism of the Second Order occur in the following Minerals: the angle is that of their latitude.

Alstonite	36° 27′	Epsomite	29° 58′	Olivenite	34° 35′
Andalusite	35° 5′	Euchroite	46° 4′	Olivine .	49° 33′
Anglesite	52° 15′	Fayalite	49° 11′	Phillipsite	34° 59′
Antimonsilber	33° 53′	Glaserite	36° 44′	Polianite	31° 0′
Antimonite	45° 36′	Goslarite	29° 58′	Pyrolusite	20° 0′
Aragonite	35° 47′	Göthite .	31° 15′	Remolinite	37° 0′
Baryte .	52° 42′	Haidingerite	26° 31′	Smithsonite	25° 47′
Bournonite	41° 54′	Harmotome	34° 47′	Stephanite	34° 26′
Brochantite	14° 4′	Karstenite	44° 25′	Strontianite	35° 54′
Caledonite	54° 31′	Leadhillite	51° 38′	Struvite	31° 34′
Celestine	52° 4′	Libethenite	35° 4′	Sulphur	62° 12′
Cerussite	35° 52′	Lölingite	48° 50′	Sylvanite	31° 26′
Chrysoberyl	30° 7′	Manganite	28° 35′	Tantalite	33° 6′
Cordierite	29° 11′	Marcasite	49° 0′	Thermonatrite	48° 5′
Cotunnite	26° 38′	Mascagnine	36° 10′	Topaz .	43° 31′
Datholite	26° 34′	Mispickel	49° 56′	Valentinite	54° 44′
Diaspore	30° 29′	Monticellite	48° 46′	Withurite	36° 33′
Epistilbite	16° 10′	Nitre .	35° 1′	Wolfram	40° 46′

The following present Cleavages parallel to this form.

Andalusite	Aragonite	Epsomite	Lolingite	*Nitre*
Antimonsilber	Bournonite	Euchroite	Marcasite	Topaz

Position of the poles of the Right Rhombic Prism of the Second Order on the Sphere of Projection.

The four poles of this prism all lie in the same meridian or zone G_1 P_1 G_2, (Fig. 307). The poles a_1, a_2 in the northern hemisphere for any particular substance are determined by observing where the circle of latitude, whose north polar distance is equal to the angle of latitude given above, cuts the meridian G_1 P_1 G_2, the other two poles are where the same circle of south latitude cuts the same meridian.

The angle for determining the latitude of the poles of this form is that given in the second column of the angular elements, for substances belonging to the prismatic system. Let β represent this angle.

Then 2β and $180° - 2\beta$ are the inclinations of the faces of this prism to each other.

Right Rhombic Prisms derived from those of the Second Order.—By increasing or diminishing the axis $P_1 P_2$ (Fig. 301), by making CP_1 (Fig. 301) equal to m times the parameter CP (Fig. 302), where m may be any whole number or fraction greater or less than unity, and then from Fig. 301 so altered constructing a right rhombic prism of the second order, a new series of prisms may be described.

Symbols.—The symbol which will represent the relation of these prisms to the axes of the prismatic system is $1 \infty m$; Naumann's is $m \breve{P} \infty$; Miller's $h\ o\ l$; Brooke and Levy's $E^{\frac{m}{2}}$.

Faces parallel to these derived Rhombic Prisms of the Second Order, with the following angles for determining the latitude of their poles, have been observed in nature.

The form $1 \infty \frac{1}{12}$; $\frac{1}{12} \breve{P} \infty$ Naumann; 1, 0, 12 Miller; $E^{\frac{1}{24}}$ Brooke and Levy.

Celestine	6° 6′

The form $1 \infty \frac{1}{6}$; $\frac{1}{6} \breve{P} \infty$ Naumann; 1 0 6 Miller; $E^{\frac{1}{12}}$ Brooke and Levy.

Tantalite	6° 11′

The form $1 \infty \frac{1}{4}$; $\frac{1}{4} \breve{P} \infty$ Naumann; 1 0 4 Miller; $E^{\frac{1}{8}}$ Brooke and Levy.

Gadolinite	16° 52′	Marcasite	16° 30′	Mispickel	16° 16′

The form $1 \infty \frac{1}{3}$; $\frac{1}{3} \breve{P} \infty$ Naumann; 1 0 3 Miller; $E^{\frac{1}{6}}$ Brooke and Levy.

Celestine	23° 9′	Marcasite	21° 33′	Sulphur	32° 18′
		Valentinite	25° 14′		

The form $1 \infty \frac{1}{2}$; $\frac{1}{2} \breve{P} \infty$ Naumann; 1 0 2 Miller; $E^{\frac{1}{4}}$ Brooke and Levy.

Antimonite	27° 4′	Ilvaite	12° 51′	Olivine	30° 24′
Aragonite	19° 49′	Leadhillite	32° 16′	Smithsonite	13° 34′
Baryte	33° 17′	Mispickel	31° 4′	Stromeycrite	25° 55′
Cerussite	19° 52′	Marcasite	30° 38′	Thermonatrite	29° 7′
Fayalite	30° 4′	Nitre	19° 19′	Witherite	20° 21′
Glaserite	56° 11′				

The form $1 \infty \frac{2}{3}$; $\frac{2}{3} \breve{P} \infty$ Naumann; 2 0 3 Miller; $E^{\frac{1}{3}}$ Brooke and Levy.

Datholite	18° 26′	Roselite	22° 30′	Topaz	32° 19′
Redruthite	32° 54′	Sulphur	51° 40′	Wolfram	29° 54′

The form $1 \infty \frac{4}{3}$; $\frac{4}{3} \breve{P} \infty$ Naumann; 4 0 3 Miller; $E^{\frac{2}{3}}$ Brooke and Levy.

Brookite	51° 32′	Datholite	33° 41′

The form $1 \infty \frac{3}{2}$; $\frac{3}{2} \breve{P} \infty$ Naumann; 3 0 2 Miller; $E^{\frac{3}{4}}$ Brooke and Levy.

Aragonite	47° 14′	Herderite	32° 30′	Staurolite	45° 48′
		Strontianite	47° 22′		

The form $1 \infty 2$; $2 \breve{P} \infty$ Naumann; 2 0 1 Miller; E^1 Brooke and Levy.

Aeschynite	53° 13′	Epsomite	49° 4′	Redruthite	62° 44′
Alstonite	55° 55′	Harmotome	54° 15′	Smithsonite	44° 0′
Antimonsilber	53° 20′	Ilvaite	42° 23′	Stephanite	53° 34′
Aragonite	55° 15′	Leadhillite	68° 24′	Sternbergite	59° 12′
Brookite	62° 6′	Mascagnine	55° 37′	Strontianite	55° 22′
Cerussite	55° 20′	Niobite	60° 20′	Sylvanite	50° 43′
Childrenite	52° 7′	Nitre	54° 30′	Topaz	62° 13′
Datholite	45° 0′	Olivine	66° 55′	Witherite	56° 0′

Cerussite, Stephanite, Strontianite, and Witherite cleave parallel to this form.

The form $1 \infty 3$; $3 \breve{P} \infty$ Naumann; 3 0 1 Miller; $E^{\frac{3}{2}}$ Brooke and Levy.

Aragonite	65° 11′	Mispickel	74° 32′	Sylvanite	61° 23′
Cerussite	65° 15′	Smithsonite	55° 23′	Tantalite	62° 58′
Datholite	56° 19′				

The form $1 \infty 4$; $4 \breve{P} \infty$ Naumann; 4 0 1 Miller; E^3 Brooke and Levy.

Cerussite	70° 55′	Strontianite	70° 57′	Topaz	75° 15′
Datholite	63° 26′	Sylvanite	67° 45′	Valentinite	79° 58′
Prehnite	73° 30′				

The form $1\ \infty\ 5$; $5\breve{P}\infty$ Naumann; 5 0 1 Miller; $E^{\frac{5}{2}}$ Brooke and Levy.

Aragonite	74° 29′	Smithsonite	67° 30′

The form $1\ \infty\ 6$; $6\breve{P}\infty$ Nauman 6 0 1 Miller; E^3 Brooke and Levy.

Aragonite	76° 59′	Herderitè	68° 34′	Strontianite	77° 2′

The form $1\ \infty\ 7$; $7\breve{P}\infty$ Naumann; 7 0 1 Miller; $E^{\frac{7}{2}}$ Brooke and Levy.

Smithsonite	73° 31′

The form $1\ \infty\ 8$; $8\breve{P}\infty$ Naumann; 8 0 1 Miller; E^4 Brooke and Levy.

Strontianite	80° 12′

The form $1\ \infty\ 10$; $10\breve{P}\infty$ Naumann; 10, 0, 1 Miller; E^5 Brooke and Levy.

Sternbergite	83° 12′

The form $1\ \infty\ 12$; $12\breve{P}\infty$ Naumann; 12, 0, 1 Miller; E^6 Brooke and Levy.

Strontianite	83° 26′

Poles of the derived Rhombic Prisms of the Second Order on the Sphere of Projection.—Let λ be the angle given in the list above for determining the latitude of any form for a particular substance. The two points where the circle of north latitude, whose polar distance from P_1 is λ, cuts the meridian or zone $G_1\ P_1\ G_2$ (Fig. 307); and the two points where the same circle of south latitude cuts the same zone, will give the four poles of the derived rhombic prism.

Let β be the angle given in the second column (pages 417, 418),

$$\tan\lambda = m\tan\beta.$$

Right Rhombic Prism of the Third Order.—The right rhombic prism of the third order is similar in form to that of the first order, but differs in position with regard to the axes.

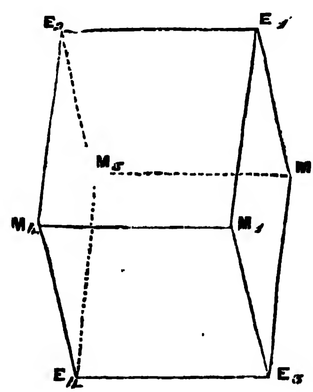


Fig. 309.

Symbols.—Each face passes through one of the extremities of the axes $P_1\ P_2$ and $H_1\ H_2$, and is parallel to the third axis $G_1\ G_2$. The *symbol* which expresses this relation is $\infty\ 1\ 1$; Naumann's is $\bar{P}\infty$; Miller's 0 1 1; Brooke and Levy's $A^{\frac{1}{2}}$.

To draw this prism prick off the points E_1, E_2, E_3, E_4 and M_1, M_2, M_3, M_4 from Fig. 301, and join them as in Fig. 309.

Faces parallel to the Prism of the Third Order occur in the following minerals: the angle is that of their latitude.

Andalusite	35° 26′	Goslarite	29° 50′	Remolinite	48° 31′
Antimonsilber	49° 19′	Göthite	33° 30′	Smithsonite	31° 40′
Aragonite	49° 10′	Ilvaite	33° 40′	Staurolite	55° 22′
Baryte	58° 10′	Liroconite	53° 49′	Stilbite	39° 8′
Bournonite	43° 43′	Lolingite	64° 20′	Struvite	48° 25′
Chrysoberyl	50° 59′	Manganite	32° 50′	Sulphur	66° 58′
Datholite	32° 17′	Mispickel	60° 24′	Sylvanite	41° 32′
Epistilbite	35° 7′	Olivenite	35° 46′	Topaz	60° 55′
Epsomite	29° 58′	Olivine	51° 33′	Wavellite	36° 37′
Eudnophite, undetermined.		Orpiment	48° 30′	Wölchite, undetermined.	
Fayalite	51° 28′	Prehnite	45° 7′	Zinckenite	14° 42′

The following present Cleavages parallel to this form.

Bournonite. Liroconite. Remolinite. ***Smithsonite.*** **Topaz.**

Position of the Poles of the Right Rhombic Prism of the Third Order on the Sphere of Projection.—Let λ be the angle given in the above list for determining the latitude for any particular substance. The two points b_1, b_2 (Fig. 307) where the circle of north latitude, whose polar distance from P_1 is λ, cuts the meridian $G_1\ PG_2$, and the two points where the same circle of south latitude cuts the same meridian, will give the four poles of the rhombic prism of the third order.

Let α be the angle given in the first column, and β that given in the second column (pages 417, 418). Then λ may be obtained from the formula

$$\tan \lambda = \frac{\tan \beta}{\tan \alpha}$$

Right Rhombic Prisms derived from those of the Third Order.—By taking CP_1 (Fig. 301) m times CP (Fig. 302) where m may be any fraction or whole number; and from Fig. 301 so altered, describing a right rhombic prism of the third order, a series of prisms similar in form and position, but differing in magnitude from Fig. 309, may be formed.

Symbols.—Each face of these derived prisms cuts two of the axes $P_1\ P_2$, $H_1\ H_2$, and is parallel to the third $G_1\ G_2$, and the symbol which expresses this relation to the axes is $\infty\ 1\ m$; Naumann's is $m\ \bar{\mathrm{P}}\ \infty$; Miller's $o\ k\ l$; and Brooke and Levy's $\mathrm{A}^{\frac{m}{2}}$

Faces parallel to these derived Rhombic Prisms of the Third Order, with the following angles for determining the latitude of their poles, have been observed in nature.

The form $\infty\ 1\ \frac{1}{6}$; $\frac{1}{6}\ \bar{\mathrm{P}}\ \infty$ Naumann; 0 1 6 Miller; $\mathrm{A}^{\frac{1}{12}}$ Brooke and Levy.

Baryte	15° 2′	Niobite	10° 0′

The form $\infty\ 1\ \frac{1}{5}$; $\frac{1}{5}\ \bar{\mathrm{P}}\ \infty$ Naumann; 0 1 5 Miller; $\mathrm{A}^{\frac{1}{10}}$ Brooke and Levy.

Baryte	17° 52′

The form $\infty\ 1\ \frac{1}{4}$; $\frac{1}{4}\ \bar{\mathrm{P}}\ \infty$ Naumann; 0 1 4 Miller; $\mathrm{A}^{\frac{1}{8}}$ Brooke and Levy.

Anglesite	22° 20′	Bournonite	13° 27′	Celestine	22° 22′
Baryte	21° 56′	Brookite	15° 40′	Leadhillite	28° 50′

The form $\infty\ 1\ \frac{1}{3}$; $\frac{1}{3}\ \bar{\mathrm{P}}\ \infty$ Naumann; 0 1 3 Miller; $\mathrm{A}^{\frac{1}{6}}$ Brooke and Levy.

Baryte	28° 14′	Cerussite	21° 33′	Sulphur	37° 58′
Celestine	28° 43′	Niobite	19° 26′	Topaz	30° 55′

The form $\infty\ 1\ \frac{1}{2}$; $\frac{1}{2}\ \bar{\mathrm{P}}\ \infty$ Naumann; 0 1 2 Miller; $\mathrm{A}^{\frac{1}{4}}$ Brooke and Levy.

Anglesite	39° 27′	Cerussite	30° 39′	Prehnite	26° 40′
Baryte	38° 51′	Epsomite	48° 47′	Strontianite	30° 43′
Bournonite	25° 33′	Glaserite	33° 5′	Sylvanite	23° 53′
Brookite	29° 18′	Haidingerite	16° 33′	Wolfram	28° 1′
Celestine	39° 24′	Leadhillite	47° 45′		

Baryte has an imperfect cleavage parallel to this form.

The form $\infty\ 1\ \frac{2}{3}$; $\frac{2}{3}\ \bar{\mathrm{P}}\ \infty$ Naumann; 0 2 3 Miller; $\mathrm{A}^{\frac{1}{3}}$ Brooke and Levy.

Bournonite	32° 31′	Chrysoberyl	39° 27′	Niobite	35° 12′

The form $\infty\ 1\ \frac{3}{4}$; $\frac{3}{4}\ \bar{\mathrm{P}}\ \infty$ Naumann; 0 3 4 Miller; $\mathrm{A}^{\frac{3}{8}}$ Brooke and Levy.

Celestine	50° 57′	Leadhillite	74° 24′

The form $\infty\ 1\ \frac{3}{2}$; $\frac{3}{2}\ \bar{P}\ \infty$ Naumann; 0 3 2 Miller; $A^{\frac{3}{4}}$ Brooke and Levy.

Datholite	43° 27′	Sylvanite	53° 2′

The form $\infty\ 1\ 2$; $2\ \bar{P}\ \infty$ Naumann; 0 2 1 Miller; A^1 Brooke and Levy.

Bournonite	62° 24′	Datholite	51° 38′	Polykrase	62° 0′
Brochantite	32° 54′	Haidingerite	49° 56′	Scorodite	65° 30′
Caledonite	71° 55′	Manganite	52° 14′	Smithsonite	50° 58′

The form $\infty\ 1\ 3$; $3\ \bar{P}\ \infty$ Naumann; 0 3 1 Miller; $A^{\frac{3}{2}}$ Brooke and Levy.

Ilvaite	63° 25′	Smithsonite	61° 37′

The form $\infty\ 1\ 4$; $4\ \bar{P}\ \infty$ Naumann; 0 4 1 Miller; A^2 Brooke and Levy.

Haidingerite	67° 11′

The form $\infty\ 1\ 6$; $6\ \bar{P}\ \infty$ Naumann; 0 6 1 Miller; A^3 Brooke and Levy.

Sternbergite	76° 31′

Position of the Poles of the derived Rhombic Prisms of the Third Order on the Sphere of Projection.—Let b_1 and b_2 (Fig. 307) be the points where the circle of latitude, whose polar distance from P_1 is the angle λ given for each particular substance in the preceding article, cuts the meridian $H_1\ PH_2$; these points, together with two similar ones where the same circle of south latitude cuts $H_1\ PH_2$, will be the four poles of the rhombic prism.

If α be the angle in the first, and β that in the second column (pages 417, 418),

$$\tan \lambda = m \frac{\tan \beta}{\tan \alpha}$$

Rhombic Pyramid.—The *double four-faced pyramid* or *octahedron on a rhombic base* is a solid bounded by eight triangular faces; each face, such as $P_1\ H_1\ G_1$ (Fig. 310) being a scalene triangle. It has six four-faced solid angles, equal to one another in pairs, that at P_1 being equal to that at P_2, at H_1 to H_2, and at G_1 to G_2. The edge $P_1\ H_1$ equals $H_1\ P_2$, $H_2\ P_2$, and $P_1\ H_2$; the edge $P_1\ G_1$ equals $P_1\ G_2$, $P_2\ G_1$, and $P_2\ G_2$; and the edge $H_1\ G_1$ equals $G_1\ H_2$, $H_2\ G_2$, and $G_2\ H_1$.

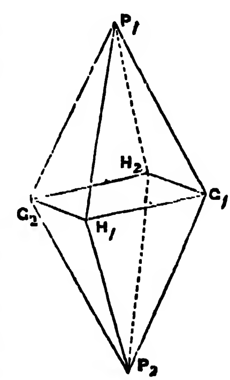


Fig. 310.

To draw the Rhombic Pyramid.—Prick off from Fig. 301 the points P_1, P_2, H_1, H_2, G_1 and G_2, and join these as in Fig. 310.

Axes.—The prismatic axes join the opposite four-faced solid angles of the rhombic pyramid.

Symbols.—Every face of the pyramid cuts the three axes $P_1\ P_2$, $G_1\ G_2$, and $H_1\ H_2$ at the extremities of the parameters; the symbol which expresses this relation is 1 1 1; Naumann's is P; Miller's 1 1 1; and Brooke and Levy's B.

Position of the Poles of the Rhombic Pyramid on the Sphere of Projection.—Four of the poles of this pyramid lie in the same parallel of north latitude, and four in the same parallel of south latitude.

Let λ be the polar distance of the pole c_1 (Fig. 307) of the face $P_1\ H_2\ G_1$ (Fig. 310) from P_1; μ its longitude from G_1 or the arc GD_1.

Then the eight poles of the rhombic pyramid will be where the north and south circles of latitude, whose polar distances are equal to λ, cut the meridians of longitude μ, $180 - \mu$, $180 + \mu$, and $360 - \mu$.

If α and β be the angles given in the first and second columns (pages 417 and 418),

Then $\mu = 90 - \alpha$, and $\tan \lambda = \tan \beta \operatorname{cosec} \alpha$.

To describe a Net for the Rhombic Pyramid.

Draw two lines, CG and CP (Fig. 311), at right angles to each other; take CP

Fig. 311.

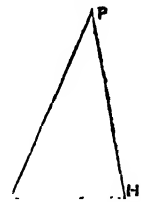


Fig. 312.

equal CP (Fig. 302), and CG and CH equal to CG and CH (Fig. 302). Join PH and PG.

Then (Fig. 312) take GH equal to GH (Fig. 302), and on GH, as a base, describe the triangle PGH, having its sides PG and PH equal to PG and PH (Fig. 311). Eight of these triangles, arranged as in Fig. 313, will give the required net.

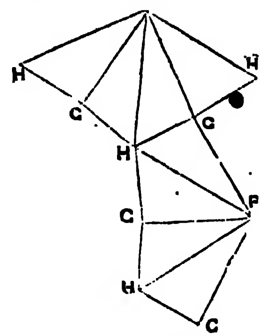


Fig. 313.

Faces parallel to the Rhombic Prism whose symbol is 1 1 1, *with the following Angles for determining the position of their Poles, have been observed in nature.*

Aeschynite	$\lambda = 48^\circ\ 28'$	$\mu = 63^\circ\ 40'$	Marcasite	$\lambda = 63^\circ\ 5'$	$\mu = 53^\circ\ 3'$
Alstonite	$\lambda = 55^\circ\ 27'$	$\mu = 59^\circ\ 26'$	Mascagnine	$\lambda = 56^\circ\ 5'$	$\mu = 60^\circ\ 34'$
Anglesite	$\lambda = 64^\circ\ 27'$	$\mu = 51\ 49'$	Mengite	$\lambda = 43^\circ\ 10'$	$\mu = 39^\circ\ 46'$
Antimonsilber	$\lambda = 53^\circ\ 26'$	$\mu = 60^\circ\ 0'$	Mesotype	$\lambda = 26^\circ\ 40'$	$\mu = 45^\circ\ 30'$
Antimonite	$\lambda = 55^\circ\ 29'$	$\mu = 45^\circ\ 23'$	Mispickel	$\lambda = 64^\circ\ 53'$	$\mu = 55^\circ\ 36'$
Aragonite	$\lambda = 53^\circ\ 44'$	$\mu = 58^\circ\ 5'$	Niobite	$\lambda = 53^\circ\ 58'$	$\mu = 50^\circ\ 20'$
Baryte	$\lambda = 64^\circ\ 18'$	$\mu = 50^\circ\ 50'$	Nitre	$\lambda = 54^\circ\ 1'$	$\mu = 59^\circ\ 25'$
Bournonite	$\lambda = 52^\circ\ 40'$	$\mu = 46^\circ\ 50'$	Olivine	$\lambda = 59^\circ\ 51'$	$\mu = 47^\circ\ 1'$
Brookite	$\lambda = 55^\circ\ 43'$	$\mu = 49^\circ\ 55'$	Orpiment	$\lambda = 52^\circ\ 3[illegible]'$	$\mu = 58^\circ\ 55'$
Caledonite	$\lambda = 64^\circ\ 17'$	$\mu = 47^\circ\ 30'$	Phillipsite	$\lambda = 45^\circ\ 0'$	$\mu = 45^\circ\ 36'$
Celestine	$\lambda = 64^\circ\ 22'$	$\mu = 52^\circ\ 1'$	Polykrase	$\lambda = 45^\circ\ 1'$	$\mu = 70^\circ\ 0'$
Cerussite	$\lambda = 54^\circ\ 14'$	$\mu = 58^\circ\ 37'$	Polymignite	$\lambda = 40^\circ\ 8'$	$\mu = 54^\circ\ 53'$
Childrenite	$\lambda = 48^\circ\ 56'$	$\mu = 55^\circ\ 57'$	Redruthite	$\lambda = 62^\circ\ 36'$	$\mu = 59^\circ\ 48'$
Chrysoberyl	$\lambda = 53^\circ\ 14'$	$\mu = 64^\circ\ 49'$	Remolinite	$\lambda = 53^\circ\ 42'$	$\mu = 56^\circ\ 10'$
Cordierite	$\lambda = 47^\circ\ 48'$	$\mu = 59^\circ\ 35'$	Roselite	$\lambda = 57^\circ\ 12'$	$\mu = 66^\circ\ 24'$
Cotunnite	$\lambda = 37^\circ\ 54'$	$\mu = 49^\circ\ 53'$	Schulzite	Unknown.	
Datholite	$\lambda = 38^\circ\ 51'$	$\mu = 51^\circ\ 38'$	Scorodite	$\lambda = 55^\circ\ 29'$	$\mu = 29^\circ\ 55'$
Diaspore	$\lambda = 40^\circ\ 57'$	$\mu = 46^\circ\ 56'$	Stephanite	$\lambda = 52^\circ\ 10'$	$\mu = 57^\circ\ 50'$
Epsomite	$\lambda = 39^\circ\ 3'$	$\mu = 45^\circ\ 17'$	Sternbergite	$\lambda = 59^\circ\ 0'$	$\mu = 59^\circ\ 45'$
Fayalite	$\lambda = 59^\circ\ 39'$	$\mu = 47^\circ\ 20'$	Stilbite	$\lambda = 48^\circ\ 0'$	$\mu = 47^\circ\ 8'$
Fluellite	$\lambda = 72^\circ\ 0'$	$\mu = 48^\circ\ 54'$	Strontianite	$\lambda = 54^\circ\ 17'$	$\mu = 58^\circ\ 40'$
Gadolonite	$\lambda = 67^\circ\ 27'$	$\mu = 59^\circ\ 45'$	Struvite	$\lambda = 52^\circ\ 6'$	$\mu = 61^\circ\ 25'$
Glaserite	$\lambda = 56^\circ\ 20'$	$\mu = 60^\circ\ 12'$	Sulphur	$\lambda = 71^\circ\ 39'$	$\mu = 50^\circ\ 59'$
Goslarite	$\lambda = 39^\circ\ 2'$	$\mu = 45^\circ\ 21'$	Sylvanite	$\lambda = 47^\circ\ 6'$	$\mu = 55^\circ\ 24'$
Göthite	$\lambda = 41^\circ\ 53'$	$\mu = 47^\circ\ 26'$	Tantalite	$\lambda = 45^\circ\ 51'$	$\mu = 50^\circ\ 46'$
Harmotome	$\lambda = 44^\circ\ 56'$	$\mu = 45^\circ\ 53'$	Thenardite	$\lambda = 61^\circ\ 51'$	$\mu = 64^\circ\ 41'$
Herderite	$\lambda = 38^\circ\ 41'$	$\mu = 57^\circ\ 57'$	Thermonatrite	$\lambda = 72^\circ\ 56'$	$\mu = 69^\circ\ 59'$
Ilvaite	$\lambda = 33^\circ\ 55'$	$\mu = 55^\circ\ 36'$	Topaz	$\lambda = 63^\circ\ 48'$	$\mu = 62^\circ\ 10'$
Karstenite	$\lambda = 55^\circ\ 50'$	$\mu = 48^\circ\ 18'$	Wavellite	$\lambda = 39^\circ\ 47'$	$\mu = 63^\circ\ 13'$
Leadhillite	$\lambda = 68^\circ\ 30'$	$\mu = 60^\circ\ 10'$	Witherite	$\lambda = 55^\circ\ 24'$	$\mu = 59^\circ\ 15'$
Libethenite	$\lambda = 45^\circ\ 23'$	$\mu = 46^\circ\ 10'$	Wolfram	$\lambda = 53^\circ\ 55'$	$\mu = 50^\circ\ 58'$
Manganite	$\lambda = 40^\circ\ 11'$	$\mu = 49^\circ\ 50'$			

Inclination of the Faces of the Rhombic Pyramid.—If θ be the angle of inclination of two faces over any of the edges HG (Fig. 310), ϕ over the edges PH, and ψ over the edges PG,

$$\theta = 2\lambda \qquad \cos\frac{\phi}{2} = \tan\beta\cos\lambda \qquad \sin\frac{\psi}{2} = \frac{\tan\beta\cos\lambda}{\tan\alpha}$$

Derived Rhombic Pyramids.—From the rhombic pyramid just described, a series of rhombic pyramids may be derived, similar in position, but differing in magnitude from the fundamental pyramid from which they are derived. These pyramids may conveniently be divided into three classes.

Derived Rhombic Pyramid of the First Class.—This pyramid is derived from the fundamental pyramid, by making the vertical axes CP_1 and CP_3 (Fig. 301) equal to m times the parameter CP (Fig. 302), where m may be any whole number, or fraction greater or less than unity.

Symbols.—The symbol for this pyramid is $1\ 1\ m$; Naumann's mP; Miller's $h\ h\ l$; and Brooke and Levy's $B^{\frac{1}{m}}$.

Inclination of Faces, Position of Poles, &c.—If the symbols α, β, λ, μ, θ, ϕ, and ψ represent the same angles as in the case of the fundamental pyramid,

$$\mu = (90° - \alpha) \qquad \tan\lambda = m \tan\beta \operatorname{cosec}\alpha$$

$$\theta = 2\lambda \qquad \cos\frac{\phi}{2} = m\tan\beta\cos\lambda \qquad \sin\frac{\psi}{2} = m\,\frac{\tan\beta\cos\lambda}{\tan\alpha}$$

The poles of this pyramid always lie in the two zones $D_1\ P_1\ D_3$ and $D_2 P_1\ D_4$ (Fig. 307), being between the points P and C when m is less than unity, and between C and D when m is greater than unity.

Faces parallel to the following Pyramids of the First Class have been observed in nature.

The form 1 1 $\frac{1}{8}$ P Naumann; 1 1 8 Miller; B^8 Brooke and Levy.

Baryte	$\lambda = 14° 34'$	$\mu = 50° 50'$

The form 1 1 $\frac{1}{6}$ P Naumann; 1 1 6 Miller; B^6 Brooke and Levy.

Anglesite	$\lambda = 19° 22'$	$\mu = 51° 49'$

The form 1 1 $\frac{1}{5}$ P Naumann; 1 1 5 Miller; B^5 Brooke and Levy.

Baryte	$\lambda = 22° 31'$	$\mu = 50° 50'$	Sulphur	$\lambda = 31° 5'$	$\mu = 50° 59'$

The form 1 1 $\frac{1}{4}$ $\frac{1}{4}$ P Naumann; 1 1 4 Miller; B^4 Brooke and Levy.

Baryte	$\lambda = 27° 27'$	$\mu = 50° 50'$	Sylvanite	$\lambda = 15° 4'$	$\mu = 55° 24'$
Celestine	$\lambda = 27° 31'$	$\mu = 52° 1'$	Topaz	$\lambda = 26° 56'$	$\mu = 62° 10'$
Stromeyerite	$\lambda = 25° 44'$	$\mu = 59° 48'$			

The form 1 1 $\frac{1}{3}$; $\frac{1}{3}$ P Naumann; 1 1 3 Miller; B^3 Brooke and Levy.

Antimonite	$\lambda = 25° 53'$	$\mu = 45° 23'$	Sulphur	$\lambda = 45° 8'$	$\mu = 50° 59'$
Baryte	$\lambda = 34° 43'$	$\mu = 50° 50'$	Sylvanite	$\lambda = 19° 44'$	$\mu = 55° 24'$
Celestine	$\lambda = 34° 47'$	$\mu = 52° 1'$	Thenardite	$\lambda = 31° 56'$	$\mu = 64° 41'$
Cerussite	$\lambda = 24° 50'$	$\mu = 58° 37'$	Topaz	$\lambda = 34° 7'$	$\mu = 62° 10'$
Karstenite	$\lambda = 26° 10'$	$\mu = 48° 18'$	Wolfram	$\lambda = 24° 35'$	$\mu = 50° 53'$
Redruthite	$\lambda = 32° 44'$	$\mu = 59° 48'$			

The form 1 1 $\frac{1}{2}$; $\frac{1}{2}$ P Naumann; 1 1 2 Miller; B^2 Brooke and Levy.

Anglesite	$\lambda = 46° 16'$	$\mu = 51° 49'$	Redruthite	$\lambda = 43° 57'$	$\mu = 59° 48'$
Antimonsilber	$\lambda = 33° 53'$	$\mu = 60° 0'$	Scorodite	$\lambda = 36° 1'$	$\mu = 29° 55'$
Baryte	$\lambda =$ 4[illegible]° 6′	$\mu = 50° 50'$	Stephanite	$\lambda = 32° 46'$	$\mu = 57° 50'$
Bournonite	$\lambda = 33° 14'$	$\mu = 46° 50'$	Strontianite	$\lambda = 34° 49'$	$\mu = 58° 40'$
Brookite	$\lambda = 36° 15'$	$\mu = 49° 55'$	Stromeyerite	$\lambda = 43° 57'$	$\mu = 59° 48'$
Cerussite	$\lambda = 34° 46'$	$\mu = 58° 37'$	Sulphur	$\lambda = 56° 26'$	$\mu = 50° 59'$
Cordierite	$\lambda = 28° 53'$	$\mu = 59° 35'$	Sylvanite	$\lambda = 28° 17'$	$\mu = 55° 24'$
Glaserite	$\lambda = 36° 54'$	$\mu = 60° 12'$	Topaz	$\lambda = 45° 28'$	$\mu = 62° 10'$
Karstenite	$\lambda = 36° 23'$	$\mu = 48° 18'$	Witherite	$\lambda = 35° 56'$	$\mu = 59° 15'$
Leadhillite	$\lambda = 51° 46'$	$\mu = 60° 10'$			

The form 1 1 $\frac{2}{3}$; $\frac{2}{3}$ P Naumann; 2 2 3 Miller; $B^{\frac{3}{2}}$ Brooke and Levy.

Caledonite	$\lambda = 54° 10'$	$\mu = 47° 30'$	Childrenite	$\lambda = 37° 25'$	$\mu = 55° 57'$

The form 1 1 $\frac{4}{5}$; $\frac{4}{5}$ P Naumann; 4 4 5 Miller; $B^{\frac{5}{4}}$ Brooke and Levy.

Strontianite	$\lambda = 43° 3'$	$\mu = 58° 40'$

The form 1 1 $\frac{4}{3}$; $\frac{4}{3}$ P Naumann; 4 4 3 Miller; $B^{\frac{3}{4}}$ Brooke and Levy.

Prehnite . . $\lambda = 68° 15'$ $\mu = 49° 58'$

The form 1 1 $\frac{3}{2}$; $\frac{3}{2}$ P Naumann; 3 3 2 Miller; $B^{\frac{2}{3}}$ Brooke and Levy.

Strontianite . $\lambda = 64° 24'$ $\mu = 58° 40'$ | Sylvanite . . $\lambda = 58° 13'$ $\mu = 55° 24'$

The form 1 1 2; 2 P Naumann; 2 2 1 Miller; $B^{\frac{1}{2}}$ Brooke and Levy.

Alstonite	$\lambda = 71° \ 0'$	$\mu = 59° 26'$	Stephanite	$\lambda = 68° 46'$	$\mu = 57° 50'$
Brookite . .	$\lambda = 71° 11'$	$\mu = 49° 55'$	Sternbergite	$\lambda = 73° 17'$	$\mu = 59° 45'$
Datholite . .	$\lambda = 58° 10'$	$\mu = 51° 38'$	Strontianite	$\lambda = 70° 14'$	$\mu = 58° 40'$
Manganite .	$\lambda = 30° 37'$	$\mu = 49° 50'$			

The form 1 1 3 3 P Naumann; 3 3 1 Miller; $B^{\frac{1}{3}}$ Brooke and Levy.

Herderite . . $\lambda = 67° 25'$ $\mu = 57° 57'$ | Strontianite . $\lambda = 76° 31'$ $\mu = 58° 40'$

The form 1 1 4; 4 P Naumann; 4 4 1 Miller; $B^{\frac{1}{4}}$ Brooke and Levy.

Datholite .	$\lambda = 72° 45'$	$\mu = 51° 38'$	Prehnite	$\lambda = 79° 13'$	$\mu = 49° 58'$
Herderite .	$\lambda = 72° 39'$	$\mu = 57° 57'$	Strontianite	$\lambda = 79° 49'$	$\mu = 58° 40'$

The form 1 1 8; 8 P Naumann; 8 8 1 Miller; $B^{\frac{1}{8}}$ Brooke and Levy.

Strontianite . $\lambda = 84° 52'$ $\mu = 58° 40'$

Derived Rhombic Pyramid of the Second Class.—This pyramid is derived from the fundamental pyramid by making the vertical axes CP_1 and CP_2 (Fig. 301) equal to m times the parameter CP (Fig. 302); where m may be any whole number or fraction, equal to, greater, or less than unity; and the lesser horizontal axes CH_1 and CH_2 (Fig. 301) equal to n times the parameter CH (Fig. 302), where n may be any whole number or fraction greater than unity.

Symbols.—The symbol for these pyramids is 1 n m; Naumann's $m \breve{P} n$; Miller's $h\ k\ l$; Brooke and Levy's $B^1 \, B^{\frac{n+1}{n-1}} \, G^{\frac{m(n+1)}{2n}}$.

Inclination of Faces, Position of Poles, &c.—If the symbols α, β, λ, μ, θ, φ, and ψ represent the same angles as in the case of the fundamental pyramid,

$$\cot \mu = n \tan \alpha \qquad \tan \lambda = m \tan \beta \sec \mu \qquad \theta = 2\lambda$$

$$\cos \frac{\phi}{2} = m \tan \beta \cos \lambda \qquad : \frac{m}{n} \frac{\tan \beta \cos \lambda}{\tan \alpha}.$$

Four of the poles E_1, E_2, E_3, and E_4 (Fig. 307) lie in the same circle of north latitude, and the other four in the same circle of south latitude, each within one of the spherical triangles GPD.

Faces parallel to the following Pyramids of the Second Class have been observed in nature.

The form 1 $\frac{8}{7}$ 2; 2 $\breve{P}$ $\frac{8}{7}$ Naumann; 8 7 4 Miller; $B^1 \, B^{15} \, G^{\frac{15}{8}}$ Brooke and Levy.

Brookite . . $\lambda = 69° 51'$ $\mu = 46° \ 7'$

The form 1 $\frac{4}{3}$ 2; 2 $\breve{P}$ $\frac{4}{3}$ Naumann; 4 3 2 Miller; $B^1 \, B^7 \, G^{\frac{7}{4}}$ Brooke and Levy.

Brookite[6] . . $\lambda = 68° 26'$ $\mu = 41° 42'$

The form 1 $\frac{3}{2}$ $\frac{3}{2}$; $\frac{3}{2}$ $\breve{P}$ $\frac{3}{2}$ Naumann; 3 2 2 Miller; $B^1 \, B^5 \, G^{\frac{5}{4}}$ Brooke and Levy.

Fayalite . .	$\lambda = 64° 59'$	$\mu = 35° 52'$	Staurolite . .	$\lambda = 60° 37'$	$\mu = 54° 37'$
Olivine . .	$\lambda = 65° 12'$	$\mu = 35° 35'$			

The form 1 $\frac{3}{2}$ 3; 3 $\breve{P}$ $\frac{3}{2}$ Naumann; 3 2 1 Miller; $B^1 \, B^3 \, G^{\frac{5}{2}}$ Brooke and Levy.

Datholite . . $\lambda = 63° \ 0'$ $\mu = 40° \ 6'$

The form 1 2 $\frac{1}{2}$; $\frac{1}{2}$ $\breve{P}$ 2 Naumann; 2 1 4 Miller; $B^1 \, B^3 \, G^{\frac{3}{8}}$ Brooke and Levy.

Baryte . . $\lambda = 37° 36'$ $\mu = 31° 33'$ Leadhillite . $\lambda = 68° 51'$ $\mu = 41° \ 5'$

The form 1 2 $\frac{2}{3}$; $\frac{2}{3}\breve{P}$ 2 Naumann; 2 1 3 Miller; $B^1 B^3 G^{\frac{1}{2}}$ Brooke and Levy.

Antimonite .	$\lambda = 37° 21'$	$\mu = 26° 52'$	Topaz	$\lambda = 41° 4'$	$\mu = 43° 26'$
Sylvanite	$= 26° 42'$	$\mu = 35° 56'$			

The form 1 2 1; $\breve{P}$ 2 Naumann; 2 1 2 Miller; $B^1 B^3 G^{\frac{3}{4}}$ Brooke and Levy.

Anglesite . .	$\lambda = 56° 51'$	$\mu = 32° 27'$	Celestine .	$\lambda = 56° 43'$	$\mu = 32° 38'$
Aragonite .	$\lambda = 42° 45'$	$\mu = 38° 45'$	Chrysoberyl	$\lambda = 46° 38'$	$\mu = 56° 47'$
Baryte .	$\lambda = 57° 0'$	$\mu = 31° 33'$	Datholite .	$\lambda = 30° 36'$	$\mu = 32° 17'$
Brookite .	$\lambda = 47° 41'$	$\mu = 59° 17'$	Leadhillite .	$\lambda = 59° 10'$	$\mu = 41° 5'$

The form 1 2 $\frac{6}{5}$; $\frac{6}{5}\breve{P}$ 2 Naumann; 6 3 5 Miller; $B^1 B^3 G^{\frac{2}{10}}$ Brooke and Levy.

Manganite . $\lambda = 37° 14'$ $\mu = 30° 38'$

The form 1 2 $\frac{4}{3}$; $\frac{4}{3}\breve{P}$ 2 Naumann; 4 2 3 Miller; $B^1 B^3 G^1$ Brooke and Levy.

Datholite . . $\lambda = 38° 15'$ $\mu = 32° 17'$

The form 1 2 2; $2\breve{P}$ 2 Naumann; 2 1 1 Miller; $B^1 B^3 G^{\frac{3}{2}}$ Brooke and Levy.

Anglesite . .	$\lambda = 71° 55'$	$\mu = 32° 27'$	Manganite	$\lambda = 51° 42'$	$\mu = 30° 38'$
Antimonite	$\lambda = 66° 24'$	$\mu = 26° 52'$	Orpiment .	$\lambda = 59° 21'$	$\mu = 39° 40'$
Aragonite .	$\lambda = 61° 35'$	$\mu = 38° 45'$	Smithsonite	$\lambda = 48° 44'$	$\mu = 32° 34'$
Brookite .	$\lambda = 65° 32'$	$\mu = 59° 17'$	Sternbergite	$\lambda = 65° 38'$	$\mu = 40° 37'$
Cerussite .	$\lambda = 61° 52'$	$\mu = 50° 40'$	Sylvanite .	$\lambda = 56° 28'$	$\mu = 35° 56'$
Chrysoberyl	$\lambda = 59° 26'$	$\mu = 56° 47'$	Topaz .	$\lambda = 69° 5'$	$\mu = 43° 26'$
Datholite .	$\lambda = 49° 47'$	$\mu = 32° 17'$	Valentinite	$\lambda = 77° 38'$	$\mu = 51° 45'$
Epistilbite	$\lambda = 42° 21'$	$\mu = 50° 29'$	Wavellite .	$\lambda = 46° 33'$	$\mu = 44° 44'$
Epsomite .	$\lambda = 51° 59'$	$\mu = 26° 49'$	Wolfram .	$\lambda = 63° 48'$	$\mu = 31° 35'$
Goslarite .	$\lambda = 52° 11'$	$\mu = 26° 43'$			

The form 1 2 4; $4\breve{P}$ 2 Naumann; 4 2 1 Miller; $B^1 B^3 G^3$ or E_3 Brooke and Levy.

Datholite . . $\lambda = 67° 5'$ $\mu = 32° 17'$

The form 1 $\frac{5}{2}$ $\frac{5}{2}$; $\frac{5}{2}\breve{P}$ $\frac{5}{2}$ Naumann; 5 2 2 Miller; $B^1 B^{\frac{7}{3}} G^{\frac{7}{4}}$ Brooke and Levy.

Göthite . . $\lambda = 58° 52'$ $\mu = 23° 32'$

The form 1 $\frac{14}{5}$ $\frac{7}{9}$; $\frac{7}{9}\breve{P}$ $\frac{14}{5}$ Naumann; 14, 5, 18 Miller; $B^1 B^{\frac{19}{9}} G^{\frac{19}{36}}$ Brooke and Levy.

Brookite . . $\lambda = 38° 35'$ $\mu = 22° 59'$

The form 1 3 $\frac{3}{8}$; $\frac{3}{8}$ P 3 Naumann; 3 1 8 Miller; $B^1 B^2 G^{\frac{1}{4}}$ Brooke and Levy.

Sylvanite . . $\lambda = 14° 27'$ $\mu = 25° 47'$

The form 1 3 $\frac{3}{5}$; $\frac{3}{5}\breve{P}$ 3 Naumann; 3 1 5 Miller; $B^1 B^2 G^{\frac{2}{5}}$ Brooke and Levy.

Celestine . .	$\lambda = 39° 50'$	$\mu = 23° 7'$	Topaz . .	$\lambda = 33° 57'$	$\mu = 32° 16'$
Sulphur . .	$\lambda = 50° 54'$	$\mu = 22° 22'$			

The form 1 3 $\frac{3}{4}$; $\frac{3}{4}\breve{P}$ 3 Naumann; 3 1 4 Miller; $B^1 B^2 G^{\frac{1}{2}}$ Brooke and Levy.

Bournonite . .	$\lambda = 35° 31'$	$\mu = 19° 34'$	Sylvanite . .	$\lambda = 26° 59'$	$\mu = 25° 47'$

The form 1 3 1; $\breve{P}$ 3 Naumann; 3 1 3 Miller; $B^1 B^2 G^{\frac{2}{3}}$ Brooke and Levy.

Antimonsilber .	$\lambda = 37° 47'$	$\mu = 30° 0'$	Sulphur . .	$\lambda = 64° 0'$	$\mu = 22° 22'$
Celestine	$\lambda = 54° 22'$	$\mu = 23° 7'$			

The form 1 3 $\frac{3}{2}$; $\frac{3}{2}\breve{P}$ 3 Naumann; 3 1 2 Miller; $B^1 B^2 G^1$ Brooke and Levy.

Baryte . .	$\lambda = 64° 49'$	$\mu = 22° 15'$	Sylvanite . .	$\lambda = 45° 31'$	$\mu = 25° 47'$
Celestine	$\lambda = 69° 50'$	$\mu = 23° 7'$			

The form 1 3 3; $3\breve{P}$ 3 Naumann; 3 1 1 Miller; $B^1 B^2 G^2$ or E_2 Brooke and Levy.

Cordierite . .	$\lambda = 62° 34'$	$\mu = 29° 35'$	Polykrase . .	$\lambda = 51° 18'$	$\mu = 42° 29'$
Niobite . .	$\lambda = 43° 26'$	$\mu = 21° 54'$			

The form 1 $\frac{10}{3}$ 5; $5\breve{P}$ $\frac{10}{3}$ Naumann; 10, 3, 2 Miller; $B^1 B^{\frac{13}{7}} G^{\frac{13}{4}}$ Brooke and Levy.

Brookite $\lambda = 72° 43'$ $\mu = 19° 37'$

The form $1\ \frac{7}{2}\ \frac{7}{2}$; $\frac{7}{2}\breve{P}\frac{7}{2}$ Naumann; 7 2 2 Miller; $B^1\ B^{\frac{9}{5}}\ G^{\frac{9}{4}}$ Brooke and Levy.
Brookite . . $\lambda = 74° \ 1'$ $\mu = 18° 45'$

The form 1 4 1; $\breve{P}\,4$ Naumann; 4 1 4 Miller; $B^1\ B^{\frac{5}{3}}\ G^{\frac{5}{8}}$ Brooke and Levy.
Celestine . . $\lambda = 53° 25'$ $\mu = 17° 48'$ | Leadhillite . $\lambda = 54° \ 2'$ $\mu = 23° 33'$
Harmotome . $\lambda = 35° 39'$ $\mu = 14° 27'$ |

The form $1\ 4\ \frac{4}{3}$; $\frac{4}{3}\breve{P}\,4$ Naumann; 4 1 3 Miller; $B^1\ B^{\frac{4}{3}}\ G^{\frac{5}{6}}$ Brooke and Levy.
Celestine . . $\lambda = 69° 23'$ $\mu = 17° 48'$ | Topaz . . $\lambda = 54° 27'$ $\mu = 25° 20'$

The form 1 4 2; $2\breve{P}\,4$ Naumann; 4 1 2 Miller; $B^1\ B^{\frac{5}{3}}\ G^{\frac{3}{4}}$ Brooke and Levy.
Anglesite . . $\lambda = 73° \ 7'$ $\mu = 17° 38'$

The form 1 4 4; $4\breve{P}\,4$ Naumann; 4 1 1 Miller; $B^1\ B^{\frac{5}{3}}\ G^{\frac{5}{2}}$ Brooke and Levy.
Datholite . . $\lambda = 64° 33'$ $\mu = 17° 32'$ | Smithsonite . $\lambda = 63° 45'$ $\mu = 17° 43'$

The form $1\ \frac{9}{2}\ \frac{9}{2}$; $\frac{9}{2}\breve{P}\frac{9}{2}$ Naumann; 9 2 2 Miller; $B^1\ B^{\frac{11}{7}}\ G^{\frac{11}{4}}$ Brooke and Levy.
Diaspore . . $\lambda = 69° 58'$ $\mu = 13° 22'$

The form 1 5 5; $5\breve{P}\,5$ Naumann; 5 1 1 Miller; $B^1\ B^{\frac{3}{2}}\ G^3$ Brooke and Levy.
Brookite . . $\lambda = 78° 22'$ $\mu = 13° 22'$ | Datholite . . $\lambda = 68° 48'$ $\mu = 14° 10'$

The form 1 6 2; $2\breve{P}\,6$ Naumann; 6 1 3 Miller; $B^1\ B^{\frac{7}{5}}\ G^{\frac{7}{6}}$ Brooke and Levy.
Niobite . . $\lambda = 60° 49'$ $\mu = 11° 22'$

Derived Rhombic Pyramid of the Third Class.—This pyramid is derived from the fundamental pyramid, by making the vertical axes CP_1 and CP_2 (Fig. 301) equal to m times the parameter CP (Fig. 302), where m may be any whole number or fraction, equal to, greater, or less than unity; and the greater horizontal axes CG_1, CG_2 (Fig. 301) equal to n times the parameter CH (Fig. 302) where n may be any whole number or fraction greater than unity.

Symbols.—The symbol for these pyramids is $n\ 1\ m$; Naumann's, $m\bar{P}n$; Miller's, $h\ k\ l$; Brooke and Levy's, $B^1\ B^{\frac{n+1}{n-1}}\ H^{\frac{m(n+1)}{2n}}$.

Inclination of Faces, position of Poles, &c.—If the symbols α, β, λ, μ, θ, ϕ, and ψ represent the same angles as in the case of the fundamental pyramid,

$$\tan\mu = n\cot\alpha \qquad \tan\lambda = \frac{m}{n}\tan\beta\sec\mu$$

$$\theta = 2\lambda \qquad \cos\frac{\phi}{2} = \frac{m}{n}\tan\beta\cos\lambda \qquad \sin\frac{\psi}{2} = m\,\frac{\tan\beta\cos\lambda}{\tan\alpha}$$

Four of the poles f_1, f_2, f_3, and f_4 (Fig. 307), lie in the same circle of north latitude, and the other four in the same circle of south latitude, whose polar distances are both equal to λ, each within one of the spherical triangles DPH.

Faces parallel to the following Pyramids of the Third Class have been observed in nature.

The form $\frac{4}{3}\ 1\ 4$; $4\bar{P}\frac{4}{3}$ Naumann; 3 4 1 Miller; $B^1\ B^7\ H^{\frac{7}{2}}$ Brooke and Levy.
Smithsonite . $\lambda = 70° 42'$ $\mu = 59° 35'$

The form $\frac{3}{2}\ 1\ \frac{1}{2}$; $\frac{1}{2}\bar{P}\frac{3}{2}$ Naumann; 2 3 6 Miller; $B^1\ B^5\ H^{\frac{5}{12}}$ Brooke and Levy.
Brookite . . $\lambda = 32° 46'$ $\mu = 60° 42'$

The form $\frac{3}{2}\ 1\ \frac{3}{4}$; $\frac{3}{4}\bar{P}\frac{3}{2}$ Naumann; 2 3 4 Miller; $B^1\ B^5\ H^{\frac{5}{8}}$ Brooke and Levy.
Anglesite . . $\lambda = 54° 18'$ $\mu = 62° 20'$

The form $\frac{3}{2}\ 1\ \frac{3}{2}$; $\frac{3}{2}\bar{P}\frac{3}{2}$ Naumann; 2 3 2 Miller; $B^1\ B^5\ H^{\frac{5}{4}}$ Brooke and Levy.
Brookite . . $\lambda = 62° 37'$ $\mu = 60° 42'$ | Tantalite . . $\lambda = 53° 43'$ $\mu = 61° 26'$

The form $\frac{5}{4}\ 1\ \frac{5}{2}$; $\frac{5}{2}\bar{P}\frac{5}{4}$ Naumann; 4 5 2 Miller; $B^1\ B^9\ H^{\frac{9}{4}}$ Brooke and Levy.

Haidingerite .	$\lambda = 60°\ 48'$	$\mu = 56°\ 7'$

The form 2 1 1; $\bar{P}\ 2$ Naumann; 1 2 2 Miller; $B^1\ B^3\ H^{\frac{3}{4}}$ Brooke and Levy.

Bournonite .	$\lambda = 46°\ 34'$	$\mu = 64°\ 52'$	Göthite . .	$\lambda = 36°\ 1'$	$\mu = 65°\ 20'$
Datholite . .	$\lambda = 34°\ 11'$	$\mu = 68°\ 24'$	Manganite .	$\lambda = 35°\ 1'$	$\mu = 67°\ 7'$
Diaspore . .	$\lambda = 34°\ 59'$	$\mu = 64°\ 57'$	Monticellite .	$\lambda = 55°\ 0'$	$\mu = 66°\ 27'$
Fayalite . .	$\lambda = 54°\ 4'$	$\mu = 65°\ 12'$	Olivine . .	$\lambda = 54°\ 15'$	$\mu = 65°\ 1'$

The form 2 1 2; $2\bar{P}\ 2$ Naumann; 1 2 1 Miller; $B^1\ B^3\ H^{\frac{3}{2}}$ Brooke and Levy.

Bournonite. .	$\lambda = 64°\ 40'$	$\mu = 64°\ 52'$	Epsomite . .	$\lambda = 52°\ 9'$	$\mu = 63°\ 40'$
Cerussite . .	$\lambda = 74°\ 18'$	$\mu = 73°\ 2'$	Ilvaite . .	$\lambda = 54°\ 38'$	$\mu = 71°\ 6'$
Chrysoberyl .	$\lambda = 68°\ 28'$	$\mu = 76°\ 46'$	Smithsonite .	$\lambda = 52°\ 57'$	$\mu = 68°\ 38'$
Datholite . .	$\lambda = 53°\ 39'$	$\mu = 68°\ 24'$	Tantalite . .	$\lambda = 59°\ 52'$	$\mu = 67°\ 47'$

The form 2 1 4; $4\bar{P}\ 2$ Naumann; 2 4 1 Miller; $B^1\ B^3\ H^3$, or A_3, Brooke and Levy.

Haidingerite .	$\lambda = 68°\ 47'$	$\mu = 67°\ 14'$

The form 3 1 1; $\bar{P}\ 3$ Naumann; 1 3 3 Miller; $B^1\ B^2\ H^{\frac{2}{3}}$ Brooke and Levy.

Manganite .	$\lambda = 38°\ 51'$	$\mu = 74°\ 17'$

The form $3\ 1\ \frac{3}{2}$; $\frac{3}{2}\bar{P}\ 3$ Naumann; 1 3 2 Miller; $B^1\ B^2\ H^1$ Brooke and Levy.

Baryte . .	$\lambda = 68°\ 14'$	$\mu = 74°\ 48'$	Mispickel . .	$\lambda = 69°\ 42'$	$\mu = 77°\ 18'$
Datholite . .	$\lambda = 44°\ 25'$	$\mu = 75°\ 13'$	Sylvanite . .	$\lambda = 91°\ 56'$	$\mu = 77°\ 3'$

The form 3 1 3; $3\bar{P}\ 3$ Naumann; 1 3 1 Miller; $B^1\ B^2\ H^2$, or A_2, Brooke and Levy.

Göthite . .	$\lambda = 64°\ 16'$	$\mu = 72°\ 59'$

The form $\frac{3}{2}\ 1\ 3$; $3\bar{P}\frac{3}{2}$ Naumann; 2 3 1 Miller; $B^1\ B^5\ H^{\frac{3}{2}}$ Brooke and Levy.

Smithsonite .	$\lambda = 64°\ 24'$	$\mu = 62°\ 27'$

The form 4 1 1; $\bar{P}\ 4$ Naumann; 1 4 4 Miller; $B^1\ B^{\frac{5}{3}}\ H^{\frac{5}{8}}$ Brooke and Levy.

Olivine . .	$\lambda = 52°\ 22'$	$\mu = 76°\ 54'$

Rhombic Sphenoid.—The *Rhombic Sphenoid*, or, *Irregular Tetrahedron*, is a *hemihedral form*, derived from the *double four-faced rhombic pyramid*, by the development of half its faces. It is bounded by four equal and similar triangular faces, each face, such as $B_1\ B_8\ B_6$ (Fig. 314), or $B_4\ B_2\ B_5$ (Fig. 315), being a scalene triangle. This solid has four three-faced solid angles, B_1, B_3, B_6, B_8 (Fig. 314), and B_2, B_4, B_5, B_7 (Fig. 315), each equal to one another; the six edges are equal to one another in pairs.

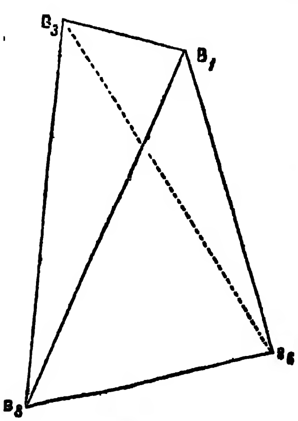


Fig. 314.

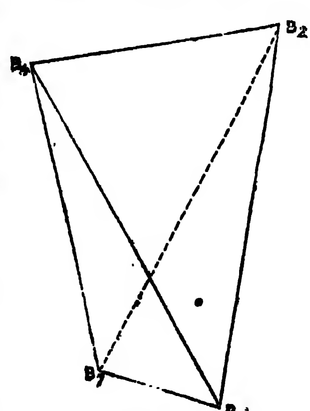


Fig. 315.

A sphenoid may be derived from every one of the pyramids previously described.

To draw the Rhombic Sphenoid.—Fig. 301 being drawn with axes P_1P_2, H_1H_2, and G_1G_2, of the requisite lengths for the pyramid; the points B_1, B_3, B_6, and B_8 being

pricked off and joined, as in Fig. 314, will give the *positive sphenoid*, and the points B_2, B_4, B_5, and B_7, joined, as in Fig. 315, will give the *negative sphenoid.*

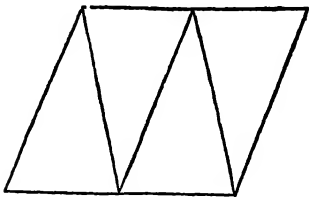


Fig. 316.

To Describe a Net for the Rhombic Sphenoid.—Let PGH (Fig. 312) be the face of the pyramid from which the sphenoid is derived; a triangle, each of whose sides is twice the corresponding side in PGH, will be a face of the derived sphenoid; and four such faces, arranged as in Fig. 316, will form the required net.

Principal Combinations of the Prismatic System.—Fig. 317. *Combination of a double four-faced rhombic pyramid with the faces of the right rectangular prism.* *a*, faces of the *pyramid*; *b*, faces of the *basal pinacoids* $\infty\ \infty\ 1$; 0 P Naumann; 0 0 1 Miller; P Brooke and Levy; replacing the solid angles P_1 and P_2 (Fig. 310) of the pyramid by planes.

c, faces of the *brachy-pinacoids* $1\ \infty\ \infty$; $\infty \breve{P} \infty$ Naumann; 1 0 0 Miller; G Brooke and Levy; replacing the solid angles G_1 and G_2 (Fig. 310) of the pyramid.

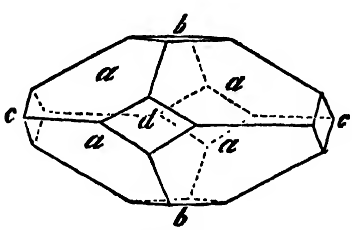


Fig. 317.

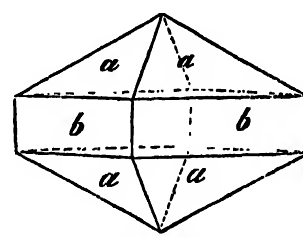


Fig. 318.

d, faces of the *macro-pinacoids* $\infty\ 1\ \infty$; $\infty \bar{P} \infty$ Naumann; 0 1 0 Miller; H Brooke and Levy; replacing the solid angles H_1 and H_2 (Fig. 310) of the pyramid.

Fig. 318. *Combination of the double four-faced rhombic pyramid with the faces of the right rhombic prism of the first order.*

If *a*, *a*, &c., represent the faces of the rhombic pyramid whose symbol is 1 1 1; P Naumann; 1 1 1 Miller; B Brooke and Levy; or of the pyramid 1 1 *m*, *m* P Naumann; *h h k* Miller; $B^{\frac{1}{m}}$ Brooke and Levy; *b*, *b*, &c., will represent the faces of the prism $1\ 1\ \infty$; ∞ P Naumann; 1 1 0 Miller; M Brooke and Levy; replacing the edges HG (Fig. 310) of the pyramid.

If *a*, *a*, &c., represent the faces of the pyramid *n* 1 *m*; $m \bar{P} n$ Naumann; *b*, *b*, &c., will represent the faces of the prism $n\ 1\ \infty$; $\infty \bar{P} n$ Naumann.

If *a*, *a*, &c., represent the faces of the pyramid 1 *n m*; $m \breve{P} n$ Naumann; *b*, *b*, &c., will represent the faces of the prism $1\ n\ \infty$; $\infty \breve{P} n$ Naumann.

Fig. 319. *Combination of the pyramid with a right rhombic prism of the second order.*

If *a*, *a*, &c., represent faces of the pyramid 1 1 *m*; *m* P Naumann; *b*, *b*, &c., will represent the faces of the prism $1\ \infty\ m$; $m \breve{P} \infty$ Naumann; replacing tde edges PG (Fig. 310) of the pyramid.

In a similar manner the faces of the prism $\infty m 1$; $m \bar{P} \infty$ Naumann; will replace the edges PH (Fig. 310) of the pyramid.

Fig. 320. *Combination of the pyramid with prisms of the first and second orders.*

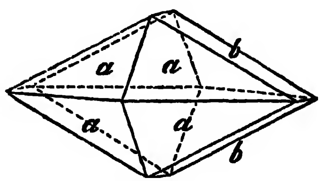


Fig. 319.

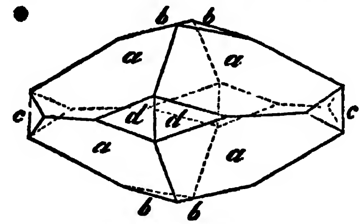


Fig. 320.

b, faces of the rhombic prism of the second order $1 \infty m$; $m \breve{P} \infty$ Naumann; replacing the solid angles P_1 P_2 (Fig. 310) of the pyramid *a*, *a*, &c., whose symbol is $1\,1\,m'$; m' P Naumann—where m' is less than m.

c, faces of the rhombic prism of the first order $1\,n\,\infty$; $\infty \breve{P} m$ Naumann; replacing the solid angles G_1, G_2 (Fig. 310), of the pyramid *a*, *a*, &c., whose symbol is $1\,n'\,m$; $\breve{m}$ P n', where n' is less than n.

d, faces of the rhombic prism of the first order $n'\,1\,\infty$; $\infty\ \bar{P}\,n$ Naumann; replacing the solid angles H_1 H_2 (Fig. 310) of the pyramid *a*, *a*, &c., whose symbol is $n'\,1\,m$; $m\ \bar{P}\ n'$ Naumann, where n' is greater than n.

Fig. 321. *Combination of the pyramid with the prisms of the second and third orders.*

b, faces of the prism of the third order $\infty\ 1\ m$; $m\ \bar{P}\ \infty$ Naumann; replacing the solid angles P_1, P_2 (Fig. 310) of the pyramid *a*, *a*, &c., whose symbol is $1\,n\,m'$, or $m'\ \breve{\bar{P}}\ n$ Naumann: or $n\,1\,m'$; $m'\ \bar{P}\ n$ Naumann, where m' is greater than m.

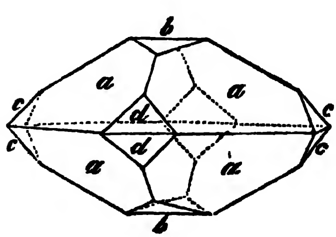


Fig. 321.

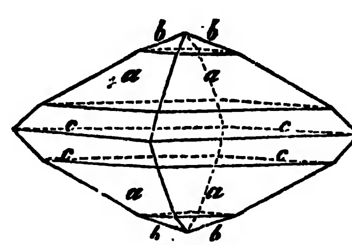


Fig. 322.

c, faces of the prism of the second order $1\ \infty\ m$; $m\ \breve{P}\ \infty$ Naumann; replacing the solid angles G_1 G_2 (Fig. 310) of the preceding pyramids, where m' is less than m.

d, faces of the prism of the third order $\infty\ 1\ m$; $m\ \bar{P}\ \infty$ Naumann; replacing the solid angles H_1 H_2 (Fig. 310) of the same pyramids, where m' is less than m.

Fig. 322. *Combinations of rhombic pyramids.*

a, faces of the pyramid $1\ n\ m$; $m\ \breve{P}\ n$ Naumann.

b, faces of the pyramid 1 *n* *m'*; $m' \breve{P} n$ Naumann; replacing the solid angles P_1 and P_2 of the pyramid *a*, *a*, &c., with a four-faced solid angle, where *m'* is less than *m*.

c, faces of the pyramid 1 *n* *m''*; $m'' \breve{P} n$ Naumann; beveling the edges HG (Fig. 310) of the pyramid *a*, *a*, &c, where *m''* is greater than *m*.

The same figure shows the combinations of the pyramid *n* 1 *m*; $m \bar{P} n$ Naumann; with the pyramids *n* 1 *m'*; m' P *n* Naumann, and *n* 1 *m''*; $m'' \bar{P} n$ Naumann under similar conditions.

Figs. 323 and 324. *Combinations of the prism of the first order with other forms.*

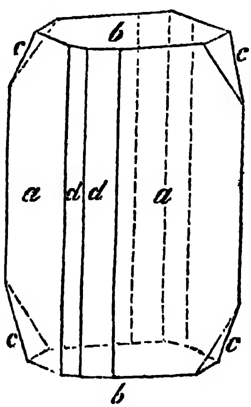


Fig. 323.

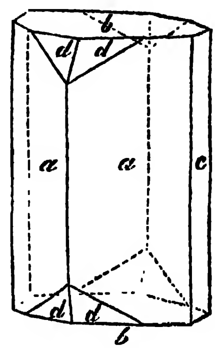


Fig. 324.

Fig. 323. *a*, faces of the prisms 1 1 ∞; ∞ P Naumann.
b, faces of the basal pinacoid ∞ ∞ 1; 0 P Naumann.
c, faces of the prism 1 ∞ 1; $\breve{P}\infty$ Naumann.
d, faces of the prism *n* 1 ∞; $\infty \bar{P} n$ Naumann.

Fig. 324. *a*, faces of the prism *n* 1 ∞; $\infty \bar{P} n$ Naumann.
b, faces of the basal pinacoid, ∞ ∞ 1; 0 P Naumann.
c, faces of the brachy pinacoid, 1 ∞ ∞; $\infty \breve{P} \infty$ Naumann.
d, faces of the pyramid 1 1 1; P Naumann.

FIFTH SYSTEM—THE OBLIQUE.

This system is called the oblique, because its forms may be derived from the oblique prism, or oblique octahedron on a rhombic base. It has also been called the *monoclinohedric*, *hemiprismatic*, *hemiorthotype*, *clinorhombic*, *hemihedric-rhombic*, and *two and one-membered* system.

The forms of this system are the *oblique prism on a rectangular base*; two orders of *prisms on rhombic bases*, a series of *right prisms on oblique rhombic bases*, and the *inclined or oblique double four-faced pyramid or octahedron on a rhombic base.*

Alphabetical list of minerals belonging to the Oblique System, with the angular elements, from which their typical forms and axes may be derived. Blanks are left in the cases where the angular elements have not been determined.

	α °	α ′	β °	β ′	γ °	γ ′
Acmite	—		—		—	
Algerite	—		—		—	
Allanite	63	40	51	15	35	45
Amphibole (hornblende)	50	35	24	27	77	13
Annabergite (arseniate of nickel)	55	9	53	57	59	11
Arfvedsonite	50	35	24	27	77	13
Augite	49	50	24	9	65	41
Barytocalcite	61	0	41	26	53	27
Bieberite (sulphate of cobalt)	31	0	44	6	50	32
Botryogen	63	5	54	29	62	41
Bragationite	63	25	51	30	35	48
Brewsterite	—		—		—	
Bronzite	49	50	24	19	65	41
Bucklandite	63	43	51	41	35	17
Chessylite (blue carbonate of copper)	45	4	47	17	58	4
Crednerite	—		—		—	
Diallage	49	50	24	9	65	41
Epidote	63	43	51	41	35	17
Erythrine (cobalt bloom)	55	9	53	57	59	12
Euclase	49	17	21	50	75	54
Felspar	65	47	50	20	63	7
Feuerblende	62	35	53	51	50	34
Freieslebenite (sulphuret of silver and antimony)	31	41	56	5	64	1
Gaylussite	73	50	27	43	55	15
Glauberite	37	23	30	53	58	10
Gypsum (sulphate of lime)	52	16	28	16	71	51
Heterosite	—		—		—	
Heulandite	43	53	47	32	73	28
Humite	64	0	36	48	37	43
Hureaulite	42	43	25	14	52	50
Hyperstene	49	50	24	19	65	41
Johannite	34	1	51	28	41	13
Kermes (red antimony)	—		—		—	
Klaprothine (lazulit)	29	25	58	50	50	10
Klinoclase (oblique prismatic arseniate of copper)	24	18	56	12	32	15
Köttigite	55	9	53	57	59	12
Laumonite	46	37	52	41	66	43
Lehmannite (chromate of lead)	39	2	38	59	59	29
Lepidolite	—		—		—	
Linarite (cupreous sulphate of lead)	74	25	28	20	50	26
Lunnite (hydrous phosphate of copper)	64	28	25	32	58	54
Margarite	—		—		—	
Malachite (green carbonate of copper)	—		—		—	
Melanterite (sulphate of iron)	31	53	43	47	50	46
Miargyrite	40	2	41	34	26	38
Mica	25	19	54	42	64	46
Mirabilite (sulphate of soda)	57	55	49	50	46	36
Monazite	39	20	36	54	59	41
Natron (carbonate of soda)	58	52	28	8	54	19
Pargasite	50	35	24	27	77	13
Pharmacolite (arseniate of lime)	54	58	28	16	73	50
Placodine	64	56	28	16	53	5
Plagionite	54	51	17	37	71	2
Realgar (red sulphuret of arsenic)	73	33	40	23	46	59
Rhodonite (siliciferous oxide of manganese)	49	50	24	9	65	41
Rhyacolite	65	37	50	29	63	19
Scheererite	—		—		—	
Scolezite (needlestone)	69	59	19	7	72	20
Sphene	34	27	60	27	68	8
Spodumene	49	50	60	40	65	33
Symplesite	—		—		—	
Tincal (borate of soda)	52	33	54	2	48	20
Triphyline	—		—		—	
Trona	—		—		—	
Vauquelinite	—		—		—	
Vivianite (phosphate of iron)	54	13	54	22	59	35
Wagnerite	63	25	44	42	56	3
Whewellite (oxalate of lime)	36	47	70	32	50	39
Woolastonite (tabular spar)	32	4	37	44	59	24
Zoisite	—		—		—	

The Oblique Rectangular Prism.—The oblique rectangular prism, or the oblique prism on a rectangular base, is a solid bounded by six faces; two of these faces (Fig. 325), B_1 B_2 B_3 B_4 and B_5 B_6 B_7 B_8, are equal and similar rectangular parallelograms; two other faces, B_1 B_2 B_6 B_5 and B_4 B_3 B_7 B_8, are also equal and similar rectangular parallelograms, differing in magnitude from the former pair; and the remaining sides, B_1 B_4 B_8 B_5 and B_3 B_2 B_6 B_7, are equal and similar oblique parallelograms.

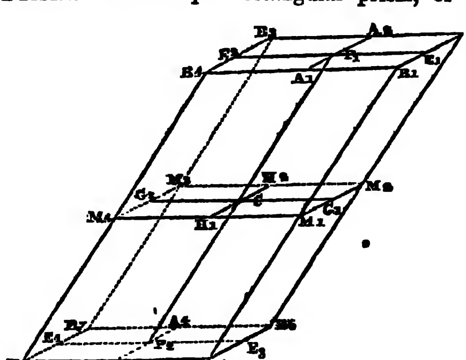


Fig. 325.

This form is now generally regarded as a combination of three open forms, each consisting of a pair of parallel faces, and sometimes appearing by

itself in combination with other forms without the other two. $B_1 B_2 B_3 B_4$ and $B_5 B_6 B_7 B_8$ are then called the *basal pinacoids*, $B_1 B_4 B_8 B_5$ and $B_2 B_3 B_7 B_6$ the *clino-pinacoids*, and $B_1 B_2 B_6 B_5$ and $B_4 B_3 B_7 B_8$ the *ortho-pinacoids*.

Axes of the Oblique Prism and Oblique System.—Bisect the edges $B_1 B_5$, $B_2 B_6$, &c., Fig. 325, by the points M_1, M_2, M_3, and M_4; the edges $B_1 B_2$, $B_4 B_3$, &c., by the points E_1, E_2, E_3, and E_4; and the edges $B_1 B_4$, $B_2 B_3$, &c., by the points A_1, A_2, A_3, and A_4.

Join M_1 M_2 M_3 and M_4; E_1 E_2 and A_1 A_2 cutting in P_1; and E_3 E_4 and A_3 A_4 cutting in P_2.

Bisect $M_1 M_2$ and $M_4 M_3$ in G_1 and G_2; and also $M_1 M_4$ and $M_2 M_3$ in H_1 and H_2.

Join $P_1 P_2$, $H_1 H_2$, and $G_1 G_2$, cutting each other in C.

Then $P_1 P_2$, $H_1 H_2$, and $G_1 G_2$, are the three *axes of the prism*, and also *of the oblique system*.

$P_1 P_2$ is called the *chief or principal axis;* $H_1 H_2$ and $G_1 G_2$ the *secondary axes.* $H_1 H_2$ is the *ortho-diagonal*, and $G_1 G_2$ the *clino-diagonal* of Naumann.

$P_1 P_2$ and $G_1 G_2$ are inclined to one another, at some angle greater or less than, but never equal to, a right angle; $H_1 H_2$ is perpendicular to both $P_1 P_2$ and $G_1 G_2$, and consequently to the plane in which they lie.

Parameters.—The semi-axes CP_1, CG_1, and CH_1, are the *parameters* of the oblique system; the length of CG_1 is perfectly arbitrary, but its length once chosen, the magnitude of CP_1 and CH_1 for any particular mineral depends upon the angular elements previously given.

To determine CP and CH. Draw CG (Fig. 326) of any convenient length.

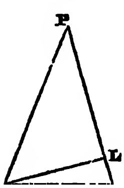


Fig. 326.

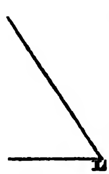


Fig. 327.

Then if α, β and γ be the three angles given as the angular elements of any particular substance,

Draw CP making an angle equal to $180° - (\alpha + \beta)$ with CG, and through G the line GP, making an angle equal to β with CG.

Let CP and GP meet in the point P; through C draw CL perpendicular to PG.

Then (Fig. 327) draw CL equal to CL (Fig. 326). Through C draw CH perpendicular to CL, and through L, LH making an angle equal to γ with CL. Let H be the point where CH and LH meet.

The lines CG, CH and CP thus determined are the *parameters* of the oblique system.

It appears, therefore, that in the oblique system *one axis only is perpendicular to the other two;* and the *three parameters are unequal.*

To draw the Oblique Rectangular Prism.—Draw $B_8 B_5$ (Fig. 325) equal to twice CG (Fig. 326). Through B_8 draw $B_8 B_7$, making an angle of about 30° with $B_8 B_7$; make $B_8 B_7$ equal CH (Fig 327), through B_5 draw $B_5 B_6$ equal and parallel to $B_8 B_7$, join $B_7 B_6$.

Through B_8 draw $B_8 B_4$ equal to twice CP (Fig. 326), and making the angle $B_4 B_8 B_5$ equal to the angle PCG (Fig. 326); through B_5, B_6 and B_7 draw $B_5 B_1$, $B_6 B_2$, and $B_7 B_3$, each parallel and equal to $B_8 B_4$. Join B_1, B_2, B_3 and B_4, and the prism will be represented in perspective.

Symbols.—Each face of the oblique rectangular prism cuts one of the three axes, at a distance from their centre, equal to the length of one of the parameters, and is parallel to the other two axes.

The two *basal pinacoids* B_1 B_2 B_3 B_4 and B_5 B_6 B_7 B_8 cut the axis P_1 P_2 in the points P_1 and P_2, and are parallel to the axes H_1 H_2 and G_1 G_2.

The symbol which represents the relation of these faces to the axes is ∞ ∞ 1.

Naumann's symbol is 0 P; Miller's, 0 0 1; Brooke and Levy's modification of Haüy is P, when they regard the oblique rhombic prism as the primitive form of the crystal.

The two *ortho-pinacoids** B_1 B_2 B_6 B_5 and B_4 B_3 B_7 B_8 cut the axis G_1 G_2 in the points G_1 and G_2, and are parallel to the axes H_1 H_2 and P_1 P_2. The symbol which represents this relation is 1 ∞ ∞

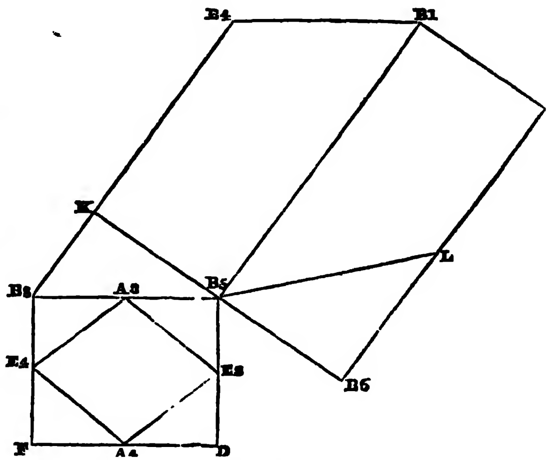


Fig. 328.

Naumann's symbol is ∞ P ∞; Miller's 1 0 0; Brooke and Levy's H.

The two *clino-pinacoids* B_1 B_4 B_8 B_5 and B_2 B_3 B_7 B_6 cut the axis H_1 H_2 in the points H_1 and H_2, and are parallel to the axes P_1 P_2 and G_1 G_2. The symbol which represents this relation is ∞ 1 ∞.

Naumann's symbol is (∞ P ∞); Miller's 0 1 0; Brooke and Levy's G.

To describe a Net for the Oblique Rectangular Prism. — Describe a parallelogram

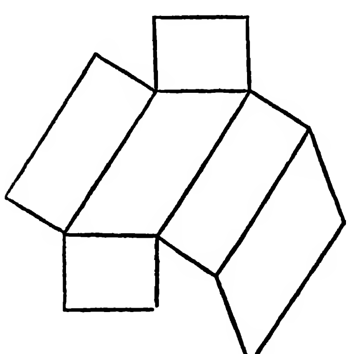


Fig. 329.

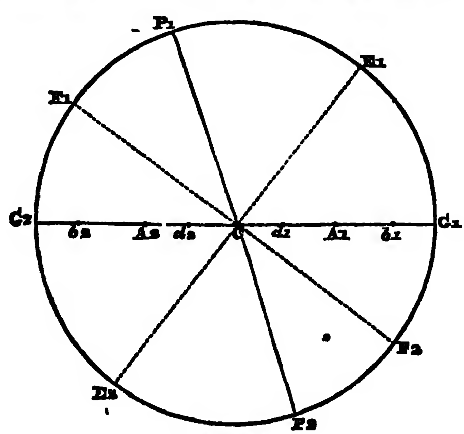


Fig. 330.

B_8 B_5 B_1 B_4 (Fig. 328) equal and similar to B_8 B_5 B_1 B_4 (Fig. 325). Through B_1 draw B_1 B_2 perpendicular to B_1 B_5, make B_1 B_2 equal to twice CH (Fig. 327). Through

B_5 draw $B_5 B_6$ perpendicular to $B_1 B_5$, making $B_5 B_6$ equal to $B_1 B_2$, and join $B_2 B_6$. Through B_8 draw B_8 F perpendicular to $B_8 B_5$, and equal to $B_5 B_6$, and through B_5, B_5 D parallel and equal to B_8 F. Join FD.

Then arrange two parallelograms equal and similar to each of the parallelograms $B_1 B_5 B_8 B_4$, $B_1 B_2 B_6 B_5$, and $B_8 B_5$ CD, as in Fig. 329, and the required net will be constructed.

Sphere of Projection for the Oblique System.—To draw a map of the sphere of projection for the oblique system, with C (Fig. 330) as a centre, and any convenient radius CG_1 describe a circle $G_1 P_1 G_2$.

Let $P_1 C P_2$, and $G_1 C G_2$ be two diameters intersecting one another in such a manner, that the angle $P_1 C G_1$ is equal to $\alpha + \beta$. Then C, the north pole of the hemisphere, may be taken as the pole of the *clino-pinacoid* $B_1 B_4 B_8 B_5$ (Fig. 325), G_1 and G_2 as the poles of the *ortho-pinacoids*, and P_1 and P_2 as the poles of the *basal pinacoids*.

Crystals of the following minerals present faces parallel to the Basal Pinacoids $\infty \infty 1$; 0 P, *Naumann*; 0 0 1, *Miller*; P, *Brooke and Levy. The angle is the longitude of the pole* P_1 *from* G_1.

Allanite	114° 55′	Glauberite . .	68° 16′	Monazite .	76° 14′
Amphibole	75° 2′	Heulandite . .	91° 25′	Pargasite .	75° 2′
Augite .	73° 59′	Humite . . .	100° 48′	Pharmacolite	83° 14′
Barytocalcite	102° 26′	Johannite . .	85° 29′	Plagionite	72° 28′
Bieberite	75° 6′	Kermes . . .	37° 45′	Realgar .	113° 55′
Botryogen	117° 34′	Klaprothine . .	88° 15′	Rhodonite	73° 59′
Bragationite	114° 55′	Klinoclase . .	80° 30′	Rhyacolite	116° 0′
Brewsterite	86° 20′	Lehmannite . .	78° 1′	Sphene .	94° 54′
Bronzite	73° 59′	Lepidolite, undetermined		Spodumene	110° 30′
Bucklandite	114° 55′	Linarite . .	102° 45′	Tincal .	106° 35′
Chessylite	92° 21′	Lunnite	90° 0′	Triphyline, undetermined.	
Epidote .	115° 24′	Malachite	61° 45′	Vauquelinite	,,
Euclase .	71° 7′	Melanterite	75° 40′	Vivianite	108° 35′
Felspar .	116° 7′	Miargyrite	81° 36′	Wagnerite	108° 7′
Freieslebenite	87° 46′	Mica	80° 1′	Whewellite	107° 19′
Gaylusite .	78° 27′	Mirabilite	107° 45′	Woolastonite	69° 48′

The following present Cleavages parallel to this form.

Bronzite	Humite	*Malachite*	*Realgar*	*Triphyline*
Epidote	*Klinoclase*	*Melanterite*	Rhodonite	Wagnerite
Felspar	Lehmannite	*Mica*	*Rhyacolite*	Whewellite
Gaylusite	*Lepidolite*	*Mirabilite*	Sphene	Woolastonite
Glauberite	Linarite	*Monazite*		

Faces parallel to the Ortho-pinacoids $1 \infty \infty$; $\infty P \infty$ *Naumann*; 1 0 0 *Miller*; H *Brooke and Levy, occur in Crystals of*

Acmite	Epidote	Humite	Malachite	Rhodonite
Algerite	Erythrine	Hureaulite	Melanterite	Rhyacolite
Allanite	Euclase	Hypersthene	Miargyrite	Scolezite
Amphibole	Felspar	Kermes	Mirabilite	Spodumene
Augite	Feuerblende	Klaprothine	Monazite	Tincal
Bragationite	Freieslebenite	Klinoclase	Natron	Vauquelinite
Brewsterite	Gaylusite	Laumonite	Placodine	Vivianite
Bronzite	Glauberite	Lehmannite	Plagionite	Wagnerite
Bucklandite	Gypsum	Linarite	Realgar	Woolastonite
Chessylite	Heulandite	Lunnite		

The following present Cleavages parallel to this form.

Acmite	*Epidote*	Laumonite	Mirabilite	*Spodumene*
Amphibole	Erythrine	Lehmannite	Monazite	*Tincal*
Augite	Euclase	*Linarite*	Placodine	Vivianite
Brewsterite	Gypsum	Lunnite	Realgar	Wagnerite
Bronzite	*Hyperstene*	Miargyrite	Rhodonite	Woolastonite
Chessylite	Kermes			

Faces parallel to the Clino-pinacoids ∞ 1 ∞; (∞ P ∞) *Naumann*; 0 1 0 *Miller*; G *Brooke and Levy, occur in Crystals of*

Acmite	Epidote	Klaprothine	Mica	Scolezite
Algerite	Erythrine	Köttigite	Mirabilite	Sphene
Amphibole	Euclase	Laumonite	Monazite	Spodumene
Annabergite	Felspar	Lehmannite	Natron	Symplesite
Arfvedsonite	Feuerblende	Lepidolite	Pargasite	Tincal
Augite	Gypsum	Linarite	Pharmacolite	Triphyline
Botryogen	Heulandite	Malachite	Realgar	Vivianite
Brewsterite	Humite	Melanterite	Rhodonite	Whewellite
Bronzite	Hyperstene	Miargyrite	Rhyacolite	Zoisite
Chessylite	Johannite			

The following present Cleavages parallel to this form.

Acmite	*Erythrine*	*Köttigite*	Monazite	Rhyacolite
Amphibole	*Euclase*	*Laumonite*	Natron	*Symplesite*
Annabergite	Felspar	Lepidolite	Pargasite	Tincal
Arfvedsonite	*Gypsum*	*Malachite*	*Pharmacolite*	Triphyline
Augite	*Heulandite*	Mica	Realgar	*Vivianite*
Brewsterite	Hyperstene	Mirabilite	Rhodonite	Whewellite
Bronzite				

Oblique Rhombic Prism of the First Order.—The *oblique rhombic prism*, or the *oblique prism on a rhombic base*, is a solid bounded by six faces, four of which are similar and equal oblique parallelograms, such as $A_1\ E_1\ E_3\ A_3$ (Fig. 331), and the other two are similar and equal rhombs.

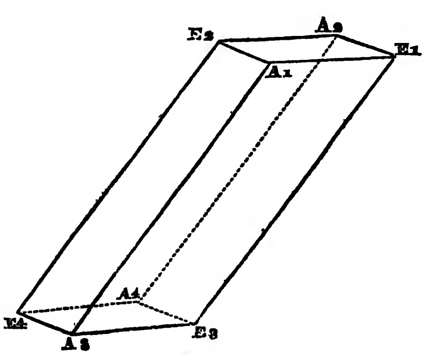


Fig. 331.

This prism is generally regarded as an open form; the four oblique parallelograms are then considered its faces, and the two rhombs which inclose it the *basal pinacoids*.

To Draw the Oblique Rhombic Prism.—Pick off the points A_1, A_2, A_3, A_4, E_1, E_2, E_3, E_4, from Fig. 325; join these points as in Fig. 331, and the prism will be represented in perspective.

...s.—Each face of this prism, considered as an open form, cuts two of the axes $G_1\ G_2$ (Fig. 325) and $H_1\ H_2$, at the extremities of their parameters, and is parallel to the third axis $P_1\ P_2$. The symbol representing this property is 1 1 ∞; Naumann's is ∞ P, Miller's 1 1 0, Brooke and Levy's M.

To Describe a Net for the Oblique Rhombic Prism of the First Order.—Bisect B_5 B_8 (Fig. 328) and F D by the points A_3 A_4, also the lines B_5 D and B_8 F by E_3 and E_4. Join E_3, A_3, E_4, and A_4; then E_4 A_3 E_3 A_4 will be the rhomb which forms the base of the prism.

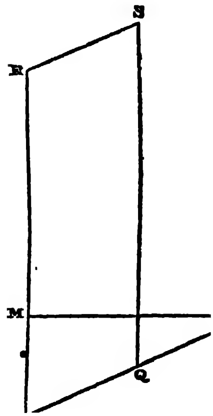


Fig. 332.

Through B_5 (Fig. 328) draw B_5 K perpendicular to B_4 B_8. In B_6 B_2 take B_6 L equal B_5 K. Join B_5 L.

Then (Fig. 332) draw M N equal B_6 L (Fig. 328), M P perpendicular to M N and equal B_6 K (Fig. 328).

Join P N, and bisect it in Q; produce P M to R, and make P R equal B_5 B_1 (Fig. 325). Through Q draw Q S parallel and equal to P R; and join R S.

P Q R S will be one of the four oblique parallelograms forming one of the sides of the prism. Four such parallelograms, and two rhombs equal A_4 E_3 A_3 E_4, arranged as in Fig. 333, will form the required net.

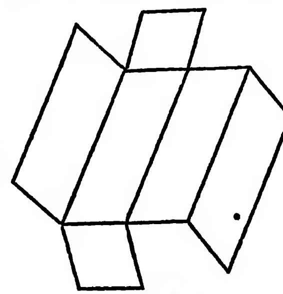


Fig. 333.

Poles of the Oblique Rhombic Prism of the First Order on the Sphere of Projection.—The four poles of this form lie in the zone or meridian G_1 C G_2 (Fig. 330): two, A_1 and A_2 (Fig. 330), where the circle of north latitude, whose polar distance from C the north pole is λ, cuts the zone G_1 C G_2; and two where the circle of south latitude, whose polar distance from the south pole is λ, cuts the same zone. λ is determined from the formula—

$$\tan. \lambda = \sin. \beta \tan. \gamma \operatorname{cosec} (\alpha + \beta),$$

where α, β, and γ are the three angles previously given as the angular elements, for the substance, whose poles for this form are required.

Poles parallel to the Oblique Rhombic Prism, 1 1 ∞; ∞ P *Naumann;* 1 1 0 *Miller;* M *Brooke and Levy, occur in the following Minerals. The angle is the angle* λ, *which determines the Latitude of their Poles.*

Acmite	43° 28′	Glauberite	41° 40′	Monazite	46° 35′
Algerite	47° 0′	Gypsum	55° 41′	Natron	38° 14′
Amphibole	62° 6′	Heulandite	68° 2′	Pargasite	62° 15′
Arfvedsonite	62° 6′	Humite	25° 15′	Pharmacolite	58° 42′
Augite	46° 33′	Hureaulite	31° 15′	Placodine	32° 16′
Barytocalcite	42° 20′	Hyperstene	43° 15′	Realgar	37° 13′
Bieberite	41° 10′	Johannite	34° 30′	Rhodonite	43° 33′
Botryogen	59° 58′	Klaprothine	45° 45′	Scolezite	45° 48′
Brewsterite	68° 0′	Klinoclase	28° 0′	Sphene	66° 54′
Bronzite	43° 33′	Laumonite	43° 8′	Spodumene	43° 30′
Bucklandite	31° 34′	Lehmannite	46° 52′	Tincal	43° 30′
Chessylite	49° 46′	Lepidolite	59° 30′	Triphyline	66° 0′
Epidote	31° 34′	Linarite	30° 30′	Vivianite	55° 36′
Euclase	57° 25′	Malachite	53° 40′	Wagnerite	47° 42′
Felspar	59° 24′	Melanterite	41° 10′	Whewellite	50° 16′
Feuerblende	69° 36′	Miargyrite	19° 49′	Woolastonite	47° 47′
Freieslebenite	59° 36′	Mica	60° 23′	Zoisite	58° 8′
Gaylussite	34° 25′	Mirabilite	40° 19′		

The following present Cleavages parallel to this prism.

Acmite	Felspar	Laumonite	*Pargasite*	Sphene
Amphibole	Freieslebenite	*Lehmannite*	Placodine	Spodumene
Arfvedsonite	*Gaylussite*	Lepidolite	Realgar	Tincal
Augite	Glauberite	Melanterite	Rhodonite	Triphyline
Botryogen	Hyperstene	Mica	*Scolezite*	Whewellite
Chessylite	Johannite	Natron		

Oblique Rhombic Prisms derived from the Oblique Rhombic Prism of the First Order $1\ 1\ \infty$, *by increasing the axis* CH_1, *or the Orthodiagonal* H_1H_2.—These prisms will be similar in magnitude and position to the prism $1\ 1\ \infty$ (Fig. 331) from which they are derived, but will differ in magnitude. To draw these prisms and describe their nets, we must make $H_1\ H_2$ (Fig. 325) equal to n times the parameter CH (Fig. 327), where n may be any whole number or fraction greater than unity. Making this alteration in Fig. 325, the points A_1, A_2, A_3, A_4, and E_1, E_2, E_3, E_4, will give the angular points of the derived prism. From Fig. 325 so altered, the net for the derived prism may be obtained in the way described for the prism $1\ 1\ \infty$.

The symbol which represents the relation of this derived prism to the axes of the oblique system is $1\ n\ \infty$; Naumann's is $\infty\ P\ n$; Miller's $k\ h\ o$; Brooke and Levy's $H^{\frac{n+1}{n-1}}$.

Position of the Poles of these derived Prisms on the Sphere of Projection.—The four poles of these prisms lie in the zone or meridian $G_1\ C\ G_2$ (Fig. 330). Two where the circle of north latitude, whose polar distance from C, the north pole, is λ, cuts the zone $G_1\ C\ G_2$, these points b_1 and b_2 always lie between $A_1\ G_1$ and $A_2\ G_2$; the other two poles will be where the circle of latitude, whose south polar distance is λ, cuts the same zone. λ is determined from the formula

$$\tan\lambda = n \sin\beta\ \tan\gamma\ \operatorname{cosec}(\alpha+\beta).$$

Faces parallel to the following forms of these Prisms have been observed; the angle given for each Mineral is λ.

The form $1\ \frac{4}{3}\ \infty$; $\infty\ P\ \frac{4}{3}$ Naumann; 4 3 0 Miller; H^7 Brooke and Levy.

Euclase	64° 24′	Freieslebenite	66° 24′	Realgar	45° 20′

The form $1\ \frac{3}{2}\ \infty$; $\infty\ P\ \frac{3}{2}$ Naumann; 3 2 0 Miller; H^5 Brooke and Levy.

Chessylite	60° 35′	Euclase	66° 55′	Placodine	43° 28′
Erythrine	65° 5′	Lehmannite	58° 1′	Wagnerite	58° 46′

The form $1\ 2\ \infty$; $\infty\ P\ 2$ Naumann; 2 1 0 Miller; H^3 Brooke and Levy.

Amphibole	62° 15′	Euclase	72° 17′	Realgar	56° 38′
Botryogen	40° 52′	Lehmannite	64° 54′	Wagnerite	65° 32′
Chessylite	67° 4′	Mirabilite	22° 59′	Zoisite	72° 41′
Epidote	50° 51′				

Botryogen has a cleavage parallel to this form.

The form $1\ \frac{5}{2}\ \infty$; $\infty\ P\ \frac{5}{2}$ Naumann; 5 2 0 Miller; $H^{\frac{7}{3}}$ Brooke and Levy.

Realgar	62° 14′

The form $1\ 3\ \infty$; $\infty\ P\ 3$ Naumann; 3 1 0 Miller; H^2 Brooke and Levy.

Amphibole	80° 3′	Freieslebenite	78° 56′	Pharmacolite	78° 33′
Augite	70° 40′	Miargyrite	45° 15′	Vivianite	77° 7′
Felspar	29° 25′				

Oblique Rhombic Prisms derived from the Oblique Prism $1\ 1\ \infty$, *by increasing the axis* CG_1, *or the Clino-diagonal* G_1G_2.—These prisms also will be similar in magnitude and position to the prism $1\ 1\ \infty$ (Fig. 331), from which they are derived; they may be drawn and their nets described by making CG_1 and CG_2 (Fig. 325) equal to n times the parameter CG (Fig. 326), where n may be any whole number or fraction greater than unity.

The symbol which represents the relation of the derived prism to the axes of the oblique system is $n\ 1\ \infty$; Naumann's is $(\infty\ P\ n)$; Miller's $h\ k\ o$; Brooke and Levy's $G^{\frac{n+1}{n-1}}$.

Position of the Poles of these derived Prisms on the Sphere of Projection.—The four poles of these prisms lie in the zone or meridian G_1CG_2 (Fig. 330), two where the circle of north latitude, whose polar distance from C, the north pole, is λ, cuts the zone G_1CG_2; these points d_1 and d_2 always lie detween CA_1 and CA_2; the other two poles will be where the circle of latitude, whose south polar distance is λ, cuts the same zone. λ is determined from the formula

$$\tan \lambda = \frac{1}{n} \sin \beta \tan \gamma \operatorname{cosec} (\alpha + \beta).$$

Faces parallel to the following forms of these Prisms have been observed; the angle given for each Mineral is λ.

The form $\frac{6}{5}\ 1\ \infty$; $(\infty\ P\ \frac{6}{5})$Naumann; 5 6 0 Miller; G^{11} Brooke and Levy.

Freieslebenite . 54° 51′

The form $\frac{4}{3}\ 1\ \infty$; $(\infty\ P\ \frac{4}{3})$ Naumann; 3 4 0 Miller; G^7 Brooke and Levy.

Erythrine 6′

The form $\frac{3}{2}\ 1\ \infty$; $(\infty\ P\ \frac{3}{2})$ Naumann; 2 3 0 Miller; G^5 Brooke and Levy.

Realgar 26° 51′

The form $\frac{5}{3}\ 1\ \infty$; $(\infty\ P\ \frac{5}{3})$ Naumann; 3 5 0 Miller; G^4 Brooke and Levy.

Freieslebenite . 45° 39′

The form $2\ 1\ \infty$; $(\infty\ P\ 2)$ Naumann; 1 2 0 Miller; G^3 Brooke and Levy.

Augite . . .	25° 25′	Gypsum . .	36° 12′	Monazite . .	27° 51′
Brewsterite . .	51° 4′	Lehmannite . .	28° 5′	Wagnerite . .	28° 47′
Chessylite . .	30° 35′	Lunnite . .	19° 28′	Whewellite . .	31° 3′
Freieslebenite .	40° 26′				

Freieslebenite and Wagnerite have cleavages parallel to this form.

The form $3\ 1\ \infty$; $(\infty\ P\ 3)$ Naumann; 1 3 0 Miller; G^2 Brooke and Levy.

Amphibole . .	32° 21′	Barytocalcite .	16° 27′	Sphene . . .	38° 1′
Augite . . .	17° 35′	Gypsum . .	26° 1′	Spodumene . .	17° 33′

Right Prism on an Oblique Rhombic Base.—This prism has two faces $A_1\ A_2\ M_2\ M_1$ (Fig. 334) $A_3\ A_4\ M_3\ M_4$, which are similar and equal rectangular parallelograms, two other faces $A_1\ A_2\ M_3\ M_4$ and $M_1\ M_2\ A_4\ A_3$ also rectangular parallelograms, and similar and equal to each other, all inclosed by the two faces $A_1\ M_1\ A_3\ M_4$ and $M_2\ A_2\ M_3\ A_4$ which are similar and equal oblique parallelograms.

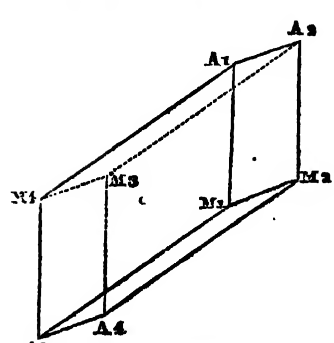


Fig. 334.

The four rectangular parallelograms are the faces of this prism when it is regarded as an open form; the oblique parallelograms which inclose it are then the faces of the clino-pinacoids.

The four faces of this prism cut the two axes $P_1\ P_2$ and $G_1\ G_2$, in the points P and G, and are parallel to the third axis $H_1\ H_2$ (Fig. 325).

The two faces $A_1\ A_2\ M_2\ M_1$ and $M_4\ M_3\ A_4\ A_3$ are called the *positive*; and $A_1\ A_2\ M_4\ M_3$, $M_1\ M_2\ A_3\ A_4$ the *negative ortho-domes*.

To draw this prism we have only to prick off the points A_1, A_2, A_3, A_4, E_1, E_2, E_3, and E_4 (Fig. 325), and join them as in Fig. 334.

Symbols.—The symbol which represents the relation of this prism to the axes of the oblique system is $1 \infty 1$; Naumann's is $P \infty$, Miller's $1\ 0\ 1$, Brooke and Levy's O^1, for the *positive ortho-domes;* and $\bar{1} \infty 1$, $-P \infty$ Naumann, $\bar{1}\ 0\ 1$ Miller, A^1 Brooke and Levy, for the *negative ortho-domes.*

Net for the Right Prism on an Oblique Rhombic Base.—Describe two oblique rhombic parallelograms similar and equal to $A_1 M_1 A_3 M_4$ (Fig. 334), two rectangular parallelograms, having their breadth equal to $A_1 M_1$ and length to twice $M_1 A_1$, and two other rectangular parallelograms of the same length, but having their breadth equal to $M_1 A_3$; arrange these six parallelograms as in Fig. 335, and the net will be constructed.

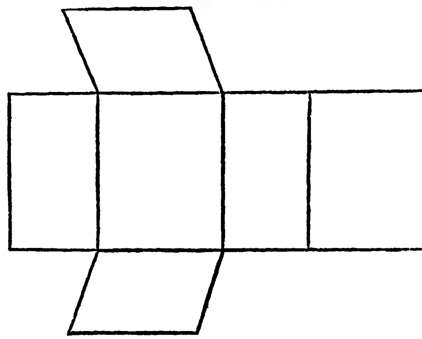


Fig. 335.

Position of the Poles of the Prism on an Oblique Rhombic Base on the Sphere of Projection.—The four poles of this prism always lie in the equator, $E_1 P_1 E_2$, Fig. 330, the poles of the positive ortho-domes between $P_1 G_1$ and $P_2 G_2$, the arc $G_1 E_1$ being equal to the arc $G_2 E_2$; F_1, F_2 the poles of the negative ortho-domes between $P_1 G_2$ and $P_2 G_1$, the arc $G_1 F_1$ being equal to $G_2 F_2$.

To determine the longitude of E_1 from G_1, we have the following formulæ:—

If ϕ be such an angle that $\tan \phi = \sin \beta \cos (\alpha + \beta) \operatorname{cosec} \alpha$,

And μ such an angle that $\cot \mu = \sin \phi \operatorname{cosec} (45° + \phi) \sin 45° \tan (\alpha + \beta)$.

Then longitude of E_1 equals $\mu + \alpha + \beta - 90$.

To determine the longitude of F_1, we have

$$\tan \phi = -\sin \beta \cos (\alpha + \beta) \operatorname{cosec} \alpha,$$

$$\text{And } \cot \mu = \sin \phi \operatorname{cosec} (45° + \phi) \sin 45° \tan (\alpha + \beta).$$

Faces parallel to the Right Prism on a Rhombic Base have been observed in the following Minerals; the angle is that of their longitude.

The form $1 \infty 1$; $P \infty$ Naumann; $1\ 0\ 1$ Miller; $O^{\frac{1}{2}}$ Brooke and Levy.

Allanite	63° 40′	Freieslebenite	31° 41′	Monazite	39° 20′
Amphibole	50° 35′	Gypsum	52° 16′	Natron	58° 52′
Augite	49° 50′	Humite	64° 0′	Placodine	64° 56′
Barytocalcite	61° 0′	Johannite	34° 1′	Realgar	73° 33′
Bieberite	31° 0′	Kermes	72° 6′	Rhyacolite	65 37′
Botryogen	63° 5′	Klaprothine	29° 25′	Sphene	34° 27′
Bragationite	63° 25′	Klinoclase	24° 18′	Triphyline	undet.
Chessylite	45° 4′	Lehmannite	39° 2′	Vauquelinite	undet.
Epidote	63° 43′	Melanterite	31° 53′	Vivianite	54° 13′
Erythrine	55° 9′	Miargyrite	40° 2′	Wagnerite	63° 25′
Euclase	49° 17′	Mirabilite	57° 55′	Whewellite	36° 47′
Felspar	65° 48′				

Euclase has a cleavage parallel to this form.

The form $\bar{1}\ \infty\ 1$; $-P\ \infty$ Naumann; $\bar{1}\ 0\ 1$ Miller; A^2 Brooke and Levy.

Amphibole	106° 2′	Hypersthene	105° 7′	Natron	126° 32′
Augite	105° 7′	Klaprothine	149° 45′	Placodine	120° 5′
Barytocalcite	134° 52′	Lehmannite	128° 58′	Sphene	148° 28′
Bieberite	138° 31′	Melanterite	137° 38′	Triphyline	undet.
Chessylite	137° 13′	Miargyrite	131° 46′	Vivianite	144° 20′
Gypsum	113° 46′	Monazite	126° 8′		

Barytocalcite has a cleavage parallel to this form.

Prisms derived from the Right Prism on an Oblique Rhombic Base.—By making CP_1 and CP_2 (Fig. 325) equal to m times the parameter CP (Fig. 326); and from (Fig. 325) so altered deriving a prism, as in Fig. 334, a new series of prisms, similar in form and position, but differing in magnitude from the prism (Fig. 334), may be formed.

m may be any fraction or whole number greater or less than unity.

The symbols for these prisms will be $\pm 1, \infty, m$; $\pm m\ P\ \infty$ Naumann; $h\ o\ k$, or $\bar{h}\ o\ k$ Miller; and $O^{\frac{m}{2}}$ or $A^{\frac{m}{2}}$ Brooke and Levy, according as the ortho-domes are positive or negative.

The formulæ for determining the longitude for the poles of these prisms, which all lie in the equator, are,

$$\tan \phi = \pm m \sin \beta \cos (\alpha + \beta) \operatorname{cosec} \alpha$$

$$\cot \mu = \sin \phi \operatorname{cosec} (45 + \phi) \sin 45 \tan (\alpha + \beta)$$

and longitude equal to $\mu + \alpha + \beta - 90$.

Faces parallel to these derived Prisms, with the following angles for determining the Longitude of their Poles, have been observed in nature.

The form $1\ \infty\ \frac{1}{8}$; $\frac{1}{8} P\ \infty$ Naumann; $1\ 0\ 8$ Miller; $O^{\frac{1}{16}}$ Brooke and Levy.

Chessylite	84° 55′	Linarite	99° 16′

The form $1\ \infty\ \frac{1}{5}$; $\frac{1}{5} P\ \infty$ Naumann; $1\ 0\ 5$ Miller; $O^{\frac{1}{10}}$ Brooke and Levy.

Chessylite	80° 32′

The form $1\ \infty\ \frac{1}{3}$; $\frac{1}{3} P\ \infty$ Naumann; $1\ 0\ 3$ Miller; $O^{\frac{1}{6}}$ Brooke and Levy.

Bucklandite	98° 38′	Kermes	102° 9′	Melanterite	54° 46′
Epidote	98° 38′	Klaprothine	58° 30′	Vivianite	89° 5′
Erythrine	89° 52′				

Erythrine has a cleavage parallel to this form.

The form $1\ \infty\ \frac{2}{5}$; $\frac{2}{5} P\ \infty$ Naumann; $2\ 0\ 5$ Miller; $O^{\frac{1}{5}}$ Brooke and Levy.

Woolastonite	49° 18′

The form $1\ \infty\ \frac{1}{2}$; $\frac{1}{2} P\ \infty$ Naumann; $1\ 0\ 2$ Miller; $O^{\frac{1}{4}}$ Brooke and Levy.

Bragationite	88° 58′	Epidote	89° 27′	Lunnite	76° 34′
Chessylite	64° 25′	Laumonite	68° 40′	Sphene	55° 33′

The form $1\ \infty\ \frac{2}{3}$; $\frac{2}{3} P\ \infty$ Naumann; $2\ 0\ 3$ Miller; $O^{\frac{1}{3}}$ Brooke and Levy.

Felspar	81° 54′	Linarite	83° 42′	Woolastonite	40° 7

The form $1\ \infty\ \frac{5}{6}$; $\frac{5}{6} P\ \infty$ Naumann; $5\ 0\ 6$ Miller; $O^{\frac{5}{12}}$ Brooke and Levy.

Linarite	78° 59′

The form $1\ \infty\ \frac{4}{3}$; $\frac{4}{3} P\ \infty$ Naumann; $4\ 0\ 3$ Miller; $O^{\frac{2}{3}}$ Brooke and Levy.

Felspar	53° 40′	Humite	54° 29′

The form $1 \infty \frac{3}{2}$; $\frac{3}{2} P \infty$ Naumann; 3 0 2 Miller; $O^{\frac{3}{2}}$ Brooke and Levy.

Allanite	34° 30′	Chessylite	33° 21′	Epidote	45° 37′

The form $1 \infty 2$; $2 P \infty$ Naumann; 2 0 1 Miller; O^1 Brooke and Levy.

Bragationite	34° 19′	Heulandite	25° 25′	Placodine	45° 15′
Chessylite	26° 9′	Humite	40° 37′	Realgar	44° 2′
Epidote	34° 21′	Lehmannite	23° 55′	Rhyacolite	35° 38′
Felspar	35° 45′	Linarite	51° 54′	Vivianite	29° 29′
Gaylussite	51° 54′	Mirabilite	32° 26′	Woolastonite	19° 30′

The form $1 \infty 3$; $3 P \infty$ Naumann; 3 0 1 Miller; $O^{\frac{1}{3}}$ Brooke and Levy.

Bragationite	22° 22′	Chessylite	18° 1′	Miargyrite	17° 38′

The form $1 \infty 4$; $4 P \infty$ Naumann; 4 0 1 Miller; O^2 Brooke and Levy.

Humite	21° 38′	Lehmannite	13° 6′

The form $\bar{1} \infty \frac{1}{3}$; $-\frac{1}{3} P \infty$ Naumann; $\bar{3}$ 0 1 Miller; A^6 Brooke and Levy.

Augite	144° 28′	Gypsum	92° 2′

The form $\bar{1} \infty \frac{1}{2}$; $-\frac{1}{2} P \infty$ Naumann; $\bar{2}$ 0 1 Miller; $A^{\frac{1}{4}}$ Brooke and Levy.

Augite	89° 20′	Laumonite	125° 41′	Lunnite	103° 26′
Chessylite	119° 16′				

The form $\bar{1} \infty \frac{2}{3}$; $-\frac{2}{3} P \infty$ Naumann; $\bar{2}$ 0 3 Miller; $A^{\frac{1}{3}}$ Brooke and Levy.

Woolastonite	114° 17′

The form $\bar{1} \infty \frac{4}{3}$; $-\frac{4}{3} P \infty$ Naumann; $\bar{4}$ 0 3 Miller; $A^{\frac{3}{4}}$ Brooke and Levy.

Humite	137° 36′

The form $\bar{1} \infty \frac{3}{2}$; $-\frac{3}{2} P \infty$ Naumann; 3 0 2 Miller; $A^{\frac{3}{4}}$ Brooke and Levy.

Erythrine	152° 31′	Glauberite	133° 46′	Klinoclase	161° 00′

The form $\bar{1} \infty 2$; $-2 P \infty$ Naumann; $\bar{2}$ 0 1 Miller; A^1 Brooke and Levy.

Amphibole	130° 6′	Glauberite	144° 39′	Mirabilite	155° 41′
Bragationite	157° 20′	Heulandite	155° 5′	Pargasite	130° 6′
Chessylite	154° 41′	Humite	147° 8′	Woolastonite	151° 25′
Felspar	157° 7′				

The form $\bar{1} \infty 3$; $-3 P \infty$ Naumann; $\bar{3}$ 0 1 Miller; $A^{\frac{3}{2}}$ Brooke and Levy.

Lehmannite	160° 41′

The form $\bar{1} \infty 4$; $-4 P \infty$ Naumann; $\bar{4}$ 0 1 Miller; A^2 Brooke and Levy.

Humite	161° 0′	Lehmannite	165° 31′

Oblique Prism on a Rhombic Base of the Second Order.—The oblique rhombic prism of the second order is similar in form to that of the first order, but differs in its position with regard to the axes of the system. The faces of this prism are called *clino-domes*.

Symbols.—Each face passes through one of the extremities of the axes $P_1 P_2$ (Fig. 325) and $H_1 H_2$, and is parallel to the third axis $G_1 G_2$. The symbol which expresses this relation is ∞ 1 1; Naumann's is ($P \infty$); Miller's 0 1 1; Brooke and Levy's $E^{\frac{1}{2}}$.

To draw this prism prick off the points E_1, E_2, E_3, E_4, and M_1, M_2, M_3, M_4, from Fig. 325, and join them as in Fig. 336.

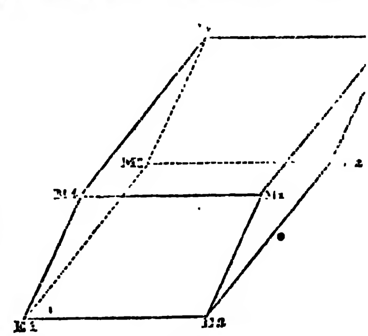


Fig. 336.

Position of the Poles of the Oblique Rhombic Prism of the Second Order on the Sphere of Projection.—The poles of this prism all lie in the zone or meridian $P_1 CP_2$ (Fig. 330);

two where the circle of north latitude, whose polar distance from c is λ, cuts the meridian $P_1\ CP_2$; and two where the circle of south latitude, whose south polar distance is λ, cuts the same zone.

The formula for determining λ is

$$\tan\lambda = \frac{\tan\gamma \sin\alpha}{\sin(\alpha+\beta)}$$

Faces parallel to the Oblique Rhombic Prism occur in the following Minerals: the angle is λ which determines the latitude of their poles.

Allanite . .	35° 25′	Humite .	35° 17′	Natron . .	55° 2′
Augite . .	60° 20′	Hureaulite	41° 0′	Pharmacolite	70° 34′
Bieberite . .	32° 55′	Klaprothine	30° 42′	Realgar	48° 21′
Bragationite . .	35° 25′	Laumonite	59° 43′	Sphene .	56° 44′
Chessylite . .	48° 41′	Lehmannite	47° 31′	Spodumene	39° 45′
Epidote . . .	35° 4′	Lunnite .	56° 18′	Vivianite	55° 33′
Feuerblende . .	37° 0′	Melanterite	33° 44′	Wagnerite	54° 25′
Freieslebenite .	47° 10′	Miargyrite	19° 9′	Whewellite	37° 25′
Gypsum . .	67° 47′	Mirabilite	43° 15′	Woolastonite	43° 44′
Heulandite . .	49° 20′	Monazite	48° 8′		

Sphene has a cleavage parallel to this form.

Oblique Rhombic Prisms derived from those of the Second Order.—By taking CP_1 and CP_2 (Fig. 325) m times the parameter CP (Fig. 326), where m may be any fraction or whole number; and from Fig. 325, so altered, describing an oblique rhombic prism of the second order, a series of prisms, similar in form and position, but differing in magnitude from Fig. 336, may be formed. The faces of these prisms are called *clino-domes.*

Symbols.—Each face of these derived prisms cuts two of the axes $P_1\,P_2$, $H_1\,H_2$, and is parallel to the third $G_1\,G_2$; the symbol which expresses this relation to the axes is $\infty\, 1\, m$; Naumann's is $(m\ P\ \infty)$; Miller's $o\ k\ l$; Brooke and Levy's $E^{\frac{m}{2}}$.

Position of the Poles of the derived Oblique Prisms of the Second Order on the Sphere of Projection.—The poles of these prisms all lie in the zone or meridian $P_1 CP_2$ (Fig. 330); two for each prism where the circle of north latitude, whose polar distance from C is λ, cuts the meridian $P_1\ CP_2$, and two where the circle of south latitude, whose south polar distance is λ, cuts the same zone.

The formula for determining λ is,

$$\tan\lambda = \frac{1}{m}\,\frac{\sin\gamma \sin\alpha}{\sin(\alpha+\beta)}.$$

Faces parallel to the derived Oblique Rhombic Prisms of the Second Order, with the following angles for determining the latitude of their poles, have been observed in nature.

The form $\infty\, 1\, \frac{1}{3}$; $(\frac{1}{3}\ P\ \infty)$ Naumann; 0 1 3 Miller; $E^{\frac{1}{6}}$ Brooke and Levy.

Melanterite . .	63° 28′	Sphene . .	77° 40′

The form $\infty\, 1\, \frac{2}{5}$; $(\frac{2}{5}\ P\ \infty)$ Naumann; 0 2 5 Miller; $E^{\frac{1}{5}}$ Brooke and Levy.

Chessylite . .	70° 38′

The form $\infty\, 1\, \frac{1}{2}$; $(\frac{1}{2}\ P\ \infty)$ Naumann; 0 1 2 Miller; $E^{\frac{1}{4}}$ Brooke and Levy.

Allanite . .	54° 53′	Euclase . . .	81° 5′	Lehmannite .	65° 24′
Bieberite . .	62° 45′	Feuerblende .	56° 26′	Realgar . .	66° 2′
Bucklandite . .	54° 33′	Freieslebenite .	65° 8′	Wagnerite .	70° 19′
Epidote . .	54° 33′	Klaprothine .	49° 45′	Woolastonite .	25° 34′

The form $\infty 1 \frac{2}{3}$; ($\frac{2}{3}$ P ∞) Naumann; 0 2 3 Miller; $E^{\frac{1}{3}}$ Brooke and Levy.

Botryogen	70° 30′	Felspar	71° 36′	Woolastonite	55° 8′
Chessylite	59° 37′	Humite	40° 43′		

The form $\infty 1 \frac{3}{2}$; ($\frac{3}{2}$ P ∞) Naumann; 0 3 2 Miller; $E^{\frac{3}{4}}$ Brooke and Levy.

Freieslebenite	35° 43′	Realgar	36° 51′	Wagnerite	42° 59′

The form ∞ 1 2; (2 P ∞) Naumann; 0 2 1 Miller; E^1 Brooke and Levy.

Amphibole	60° 26′	Gaylussite	35° 15′	Monazite	29° 9′
Augite	41° 27′	Humite	19° 29′	Rhyacolite	45° 16′
Chessylite	29° 37′	Lehmannite	28° 38′	Tincal	24° 51′
Felspar	45° 3′	Mica	24° 45′	Wagnerite	34° 57′
Freieslebenite	28° 21′				

Chessylite has a perfect cleavage parallel to this form.

The form ∞ 1 4; (4 P ∞) Naumann; 0 4 1 Miller; E^2 Brooke and Levy.

Augite	23° 42′

The form ∞ 1 6; (6 P ∞) Naumann; 0 6 1 Miller; E^3 Brooke and Levy.

Felspar	18° 28′

Oblique Rhombic Octahedron.—The *oblique rhombic octahedron*, or the *double four-faced oblique pyramid on a rhombic base*, which is also called the *monoclinohedric pyramid*, is a solid bounded by eight scalene triangles. These triangular faces are of two kinds; the faces $P_1 H_1 G_1$ (Fig. 337), $P_1 H_2 G_2$, $P_2 H_1 G_2$, and $P_2 H_2 G_2$, being equal and similar scalene triangles; and the faces $P_1 G_2 H_1$, $P_1 H_2 G_2$, $P_2 H_1 G_1$, and $P_2 H_2 G_1$ being also similar and equal scalene triangles, which are not similar or equal to the former. This solid may be regarded as a combination of two open forms, each consisting only of those faces which are similar and equal to each other.

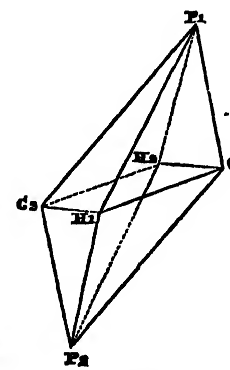


Fig. 337

To draw the Oblique Rhombic Octahedron.—Prick off from Fig. 325 the points P_1, P_2, H_1, H_2, G_1, G_2, and join these as in Fig. 337.

Axes.—The axes of the oblique system join the points $P_1 P_2$, $H_1 H_2$, and $G_1 G_2$, Fig. 337.

Symbols.—Every face of the pyramid cuts the three axes $P_1 P_2$, $H_1 H_2$, and $G_1 G_2$, at the extremities of the parameters.

1 1 1 may be taken as the symbol for the form whose faces are $P_1 H_1 G_1$, $P_1 H_2 G_1$, $P_2 H_1 G_2$, and $P_2 H_2 G_2$. Naumann's symbol for this form is P; Miller's, 1 1 1; Brooke and Levy's, D. This form is called the *positive hemi-pyramid*.

$\bar{1}$ 1 1 may be taken as the symbol for the form whose faces are $P_1 H_1 G_2$, $P_1 H_2 G_2$, $P_1 H_1 G_1$, and $P_2 H_2 G_1$. Naumann's is — P; Miller's, $\bar{1}$ 1 1; Brooke and Levy's B. This form is called the *negative hemi-pyramid*.

Position of the Poles on the Sphere of Projection.—Two of the poles of each of these forms lie in the same circle of north latitude, and two in the circle of south latitude, whose south polar distance λ is equal to the north polar distance of the former.

Let μ be the longitude of the pole nearest to G_1 (Fig. 330) on the northern hemisphere, reckoning its longitude from G_1, of the form 1 1 1, the four poles of this form will be where the circles of latitude whose north and south polar distances are λ cut the meridians μ and 180 + μ.

If μ be the longitude of the nearest pole of $\bar{1}\ 1\ 1$ to G_2, reckoning its longitude from G_1, its four poles will be where the circles of latitude, whose north and south polar distances are λ, cut the meridians μ and $180 + \mu$.

The following formulæ are used for the determination of λ and μ for the form 1 1 1.

If ϕ be such an angle that $\tan\phi = \sin\beta\cos(\alpha+\beta)\operatorname{cosec}\alpha$

and ψ such that $\cot\psi = \sin\phi\operatorname{cosec}(45+\phi)\sin 45\tan(\alpha+\beta)$

Then $\mu = \psi + \alpha + \beta - 90^\circ$ and $\tan\lambda = \sin\beta\tan\gamma\sec\psi$

For the form $1\ 1\ \bar{1}$ the formulæ are the same, except that

$$\tan\phi = -\sin\beta\cos(\alpha+\beta)\operatorname{cosec}\alpha.$$

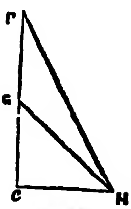


Fig. 338.

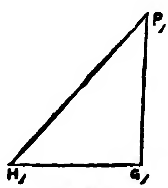


Fig. 339.

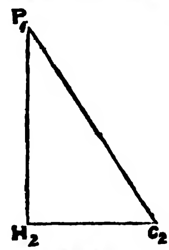


Fig. 340.

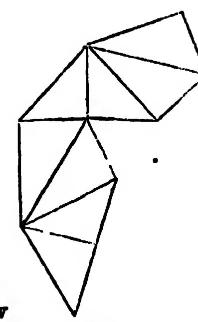


Fig. 341.

To describe a Net for the Oblique Rhombic Octahedron.—Draw CH and CP (Fig. 338) at right angles to each other; take CH and CP equal to the parameters CH and CP (Figs. 326 and 327), and in CP take CG equal to the parameter CG (Fig. 326). Join HG and HP.

Then (Fig. 339) describe the triangle $H_1\ P_1\ G_1$, having its sides $H_1\ G_1$ and $H_1\ P_1$ equal to HG and HP (Fig. 338), and the side $G_1\ P_1$ equal to a line joining G_1 and P_1 (Fig. 325).

Likewise (Fig. 340) describe the triangle $H_2\ P_1\ G_2$, having its sides $H_2\ G_2$ and $H_2\ P_1$ equal to HG and HP (Fig. 338), and the side $G_2\ P_1$ equal to a line joining G_2 and P_1 (Fig. 325).

Then four triangles equal and similar to $P_1\ H_1\ G_1$ (Fig. 339), and four other equal and similar to $P_1\ H_2\ G_2$ (Fig. 340) arranged as in Fig. 341, will form the required net.

Faces parallel to the Positive Hemipyramid 1 1 1; P *Naumann*; 1 1 1 *Miller*; D *Brooke and Levy, have been observed in the following Minerals.*

Allanite .	$\lambda = 35^\circ 45'$	$\mu = 63^\circ 40'$	Laumonite .	$\lambda = 66^\circ 43'$	$\mu = 46^\circ 37'$
Amphibole	$\lambda = 77^\circ 13'$	$\mu = 50^\circ 35'$	Lehmannite .	$\lambda = 59^\circ 29'$	$\mu = 39^\circ 2'$
Augite .	$\lambda = 65^\circ 42'$	$\mu = 49^\circ 50'$	Lunnite . .	$\lambda = 58^\circ 54'$	$\mu = 64^\circ 28'$
Barytocalcite	$\lambda = 53^\circ 27'$	$\mu = 61^\circ 0'$	Melanterite .	$\lambda = 50^\circ 46'$	$\mu = 31^\circ 53'$
Botryogen .	$\lambda = 62^\circ 41'$	$\mu = 63^\circ 5'$	Miargerite .	$\lambda = 26^\circ 38'$	$\mu = 40^\circ 2'$
Bragationite	$\lambda = 35^\circ 48'$	$\mu = 63^\circ 25'$	Mica . . .	$\lambda = 64^\circ 46'$	$\mu = 25^\circ 19'$
Chessylite	$\lambda = 58^\circ 3'$	$\mu = 45^\circ 4'$	Mirabilite . .	$\lambda = 46^\circ 36'$	$\mu = 57^\circ 55'$
Epidote	$\lambda = 35^\circ 16'$	$\mu = 63^\circ 43'$	Monazite . .	$\lambda = 59^\circ 41'$	$\mu = 39^\circ 20'$
Erythrine	$\lambda = 59^\circ 12'$	$\mu = 55^\circ 9'$	Plagionite . .	$\lambda = 71^\circ 1'$	$\mu = 54^\circ 51'$
Euclase	$\lambda = 75^\circ 54'$	$\mu = 49^\circ 17'$	Realgar . .	$\lambda = 46^\circ 59'$	$\mu = 76^\circ 33'$
Felspar	$\lambda = 63^\circ 7'$	$\mu = 65^\circ 48'$	Rhyacolite . .	$\lambda = 63^\circ 19'$	$\mu = 65^\circ 37'$
Freieslebenite	$\lambda = 64^\circ 1'$	$\mu = 31^\circ 41'$	Scolezite . .	$\lambda = 72^\circ 20'$	$\mu = 69^\circ 59'$
Gaylussite .	$\lambda = 55^\circ 15'$	$\mu = 73^\circ 50'$	Spodumene .	$\lambda = 45^\circ 33'$	$\mu = 49^\circ 50'$
Glauberite	$\lambda = 58^\circ 10'$	$\mu = 37^\circ 23'$	Tincal . .	$\lambda = 48^\circ 20'$	$\mu = 52^\circ 33'$
Gypsum .	$\lambda = 71^\circ 51'$	$\mu = 52^\circ 16'$	Vauquelinite, not determined.		
Heulandite	$\lambda = 73^\circ 28'$	$\mu = 43^\circ 53'$	Vivianite . .	$\lambda = 59^\circ 35'$.	$\mu = 54^\circ 13'$
Humite .	$\lambda = 37^\circ 43'$	$\mu = 64^\circ 0'$	Wagnerite .	$\lambda = 56^\circ 3'$	$\mu = 63^\circ 25'$
Klaprothine	$\lambda = 50^\circ 10'$	$\mu = 29^\circ 25'$	Woolastonite .	$\lambda = 59^\circ 24'$	$\mu = 32^\circ 4'$

Barytocalcite has a perfect cleavage parallel to this form.

Faces parallel to the Negative Hemipyramid $\bar{1}\,1\,1$; $-$P *Naumann*; $\bar{1}\,1\,1$ *Miller*; B *Brooke and Levy, have been observed in the following Minerals.*

Allanite .	$\lambda = 48^\circ\ 18'$	$\mu = 144^\circ\ 56'$	Klaprothine .	$\lambda = 49^\circ\ 25'$	$\mu = 149^\circ\ 45'$
Amphibole	$\lambda = 74^\circ\ 14'$	$\mu = 106^\circ\ 2'$	Lehmannite .	$\lambda = 53^\circ\ 57'$	$\mu = 128^\circ\ 58'$
Augite .	$\lambda = 60^\circ\ 16'$	$\mu = 105^\circ\ 7'$	Mica . .	$\lambda = 61^\circ\ 27'$	$\mu = 150^\circ\ 27'$
Chessylite	$\lambda = 59^\circ\ 8'$	$\mu = 137^\circ\ 13'$	Mirabilite .	$\lambda = 55^\circ\ 21'$	$\mu = 141^\circ\ 42'$
Epidote	$\lambda = 48^\circ\ 5'$	$\mu = 145^\circ\ 17'$	Monazite .	$\lambda = 53^\circ\ 18'$	$\mu = 126^\circ\ 8'$
Euclase	$\lambda = 71^\circ\ 55'$	$\mu = 99^\circ\ 59'$	Pargasite .	$\lambda = 74^\circ\ 14'$	$\mu = 106^\circ\ 2'$
Felspar	$\lambda = 72^\circ\ 20'$	$\mu = 145^\circ\ 2'$	Plagionite .	$\lambda = 67^\circ\ 13'$	$\mu = 94^\circ\ 9'$
Glauberite	$\lambda = 47^\circ\ 41'$	$\mu = 117^\circ\ 6'$	Scolezite .	$\lambda = 72^\circ\ 10'$	$\mu = 108^\circ\ 25'$
Gypsum	$\lambda = 69^\circ\ 14'$	$\mu = 113^\circ\ 46'$	Vivianite .	$\lambda = 67^\circ\ 7'$	$\mu = 144^\circ\ 20'$
Humite	$\lambda = 42^\circ\ 39'$	$\mu = 131^\circ\ 0'$	Wagnerite .	$\lambda = 63^\circ\ 46'$	$\mu = 130^\circ\ 7'$

Augite has a cleavage parallel to this form.

Derived Oblique Rhombic Octahedrons.—From the oblique rhombic octahedron just described, a series of oblique rhombic octahedrons may be derived, similar to it in position, but differing in magnitude. These octahedrons may conveniently be arranged under three classes.

Derived Oblique Octahedron of the First Class.—These pyramids may be drawn by making CP_1 and CP_2 (Fig. 325) equal to m times the parameter CP (Fig. 326), where m may be any whole number or fraction greater or less than unity.

Symbols.—The symbol for the positive hemipyramid is 1 1 m; m P Naumann; $h\ h\ l$ Miller; D^m Brooke and Levy. For the negative hemipyramid $\bar{1}$ 1 m; $-m$ P, Naumann; B^m Brooke and Levy.

Poles.—The poles of the positive hemipyramids lie in the zone $E_1\ CE_2$ (Fig. 330), and those of the negative in the zone $F_1\ CF_2$. To determine λ and μ we have the following formulæ:—

$$\tan\phi = \pm\, m \sin\beta \cos(\alpha + \beta) \operatorname{cosec}\alpha$$
$$\cot\psi = \sin\phi \operatorname{cosec}(45 + \phi) \sin 45 \tan(\alpha + \beta)$$
$$\mu = \psi + \alpha + \beta - 90 \quad \text{and} \quad \tan\lambda = \sin\beta \tan\gamma \sec\psi.$$

Faces parallel to the following Pyramids of the First Class have been observed in Nature.

The form 1 1 $\frac{1}{10}$; $\frac{1}{10}$ P Naumann; 1, 1, 10 Miller; D^{10} Brooke and Levy.

Miargyrite .	$\lambda = 73^\circ\ 12'$	$\mu = 75^\circ\ 49'$

The form 1 1 $\frac{1}{6}$; $\frac{1}{6}$ P Naumann; 1 1 6 Miller; D^6 Brooke and Levy.

Miargyrite . .	$\lambda = 63^\circ\ 51'$	$\mu = 72^\circ\ 13'$

The form 1 1 $\frac{1}{4}$; $\frac{1}{4}$ P Naumann; 1 1 4 Miller; D^4 Brooke and Levy.

Miargyrite	$\lambda = 54^\circ\ 26'$	$\mu = 67^\circ\ 50'$

The form 1 1 $\frac{1}{3}$; $\frac{1}{3}$ P Naumann; 1 1 3 Miller; D^3 Brooke and Levy.

Klaprothine	$\lambda = 64^\circ$	$\mu = 58^\circ\ 30'$	Sphene . .	$\lambda = 78^\circ\ 30'$	$\mu = 60^\circ\ 52'$
Miargyrite .	$\lambda = 47^\circ$	$\mu = 63^\circ\ 37'$			

The form 1 1 $\frac{1}{2}$ $\frac{1}{2}$ P Naumann; 1 1 2 Miller; D^2 Brooke and Levy.

Bucklandite	$\lambda = 51^\circ\ 45'$	$\mu = 89^\circ\ 27'$	Mica . .	$\lambda = 70^\circ\ 4'$	$\mu = 41^\circ\ 7'$
Epidote .	$\lambda = 51^\circ\ 45'$	$\mu = 89^\circ\ 27'$	Plagionite .	$\lambda = 60^\circ\ 24'$	$\mu = 42^\circ\ 29'$
Felspar .	$\lambda = 74^\circ\ 28'$	$\mu = 91^\circ\ 9'$	Sphene .	$\lambda = 74^\circ\ 49'$	$\mu = 55^\circ\ 33'$
Freieslebenite	$\lambda = 70^\circ\ 21'$	$\mu = 50^\circ\ 30'$	Spodumene	$\lambda = 58^\circ\ 0'$	$\mu = 76^\circ\ 46'$
Humite .	$\lambda = 54^\circ\ 34'$	$\mu = 81^\circ\ 33'$	Tincal .	$\lambda = 61^\circ\ 17'$	$\mu = 76^\circ\ 49'$
Klaprothine	$\lambda = 57^\circ\ 45'$	$\mu = 47^\circ\ 55'$	Vivianite .	$\lambda = 70^\circ\ 26'$	$\mu = 79^\circ$
Miargyrite	$\lambda = 37^\circ\ 49'$	$\mu = 56^\circ\ 11'$	Wagnerite	$\lambda = 69^\circ\ 27'$	$\mu = 85^\circ$

Plagionite has a perfect cleavage parallel to this form.

The form 1 1 $\frac{2}{3}$; $\frac{2}{3}$ P Naumann; 2 2 3 Miller; $D^{\frac{3}{2}}$ Brooke and Levy.

Chessylite .	$\lambda = 63^\circ\ 49'$	$\mu = 56^\circ\ 57'$

The form 1 1 P Naumann; 2 2 1 Miller; $D^{\frac{1}{2}}$ Brooke and Levy.

Augite	$\lambda = 55° 35'$	$\mu = 35° 39'$	Humite	$\lambda = 28° 6'$	$\mu = 40° 37'$
Chessylite	$\lambda = 52° 13'$	$\mu = 26° 9'$	Woolastonite	$\lambda = 53° 22'$	$\mu = 19° 30'$
Felspar	$\lambda = 57° 0'$	$\mu = 35° 45'$			

The form 1 1 3; 3 P Naumann; 3 3 1 Miller; $D^{\frac{1}{3}}$ Brooke and Levy.

Euclase	$\lambda = 65° 8'$	$\mu = 27° 51'$

The form 1 1 4; 4 P Naumann; 4 4 1 Miller; $D^{\frac{1}{4}}$ Brooke and Levy.

Lehmannite	$\lambda = 49° 4'$	$\mu = 13° 16'$

The form $\bar{1}$ 1 $\frac{1}{2}$; $-\frac{1}{2}$ P Naumann; 1 1 2 Miller; B^2 Brooke and Levy.

Bragationite	$\lambda = 60° 37'$	$\mu = 133° 27'$	Vivianite	$\lambda = 74° 41'$	$\mu = 130° 51'$
Miargyrite	$\lambda = 34° 33'$	$\mu = 110° 30'$	Whewellite	$\lambda = 65° 39'$	$\mu = 138° 40'$

The form $\bar{1}$ 1 $-\frac{1}{3}$ P Naumann; 1 1 3 Miller; B^3 Brooke and Levy.

Glauberite	$\lambda = 71° 22'$	$\mu = 84° 27'$	Klaprothine	$\lambda = 63° 32'$	$\mu = 118° 58'$
Gypsum	$\lambda = 82° 8'$	$\mu = 92° 2'$			

The form 1 1 2; -2 P Naumann, 2 2 1 Miller; $B^{\frac{1}{2}}$ Brooke and Levy.

Amphibole	$\lambda = 65° 48'$	$\mu = 130° 6'$	Miargyrite	$\lambda = 19° 22'$	$\mu = 152° 48'$
Augite	$\lambda = 47° 45'$	$\mu = 129° 18'$	Wagnerite	$\lambda = 50° 51'$	$\mu = 153° 14'$
Chessylite	$\lambda = 53° 7'$	$\mu = 154° 44'$	Woolastonite	$\lambda = 46° 7'$	$\mu = 154° 25'$
Humite	$\lambda = 32° 38'$	$\mu = 117° 8'$			

The form 1 1 3; -3 P Naumann; 3 3 1 Miller; $B^{\frac{1}{3}}$ Brooke and Levy.

Augite	$\lambda = 41° 4'$	$\mu = 143° 17'$	Glauberite	$\lambda = 71° 22'$	$\mu = 84° 27'$

Derived Oblique Octahedron of the Second Class.—This octahedron may be drawn and its net described, by making CP_1 and CP_2 (Fig. 325) m times the parameter CP (Fig. 326); where m may be any whole number or fraction equal to, greater, or less than unity: and CH_1 and CH_2 (Fig. 325) n times the parameter CH (Fig. 327), where n may be any whole number or fraction greater than unity.

Symbols.—The symbol for the positive hemipyramid of this octahedron is 1 n m; m P n Naumann; $h\ k\ l$ Miller; $D^1 D^{\frac{n+1}{n-1}} H^{\frac{m(n+1)}{2n}}$ Brooke and Levy: for the negative hemipyramid $\bar{1}\ n\ m$; $-m$ P n Naumann; $\bar{h}\ k\ l$ Miller; $B^1 B^{\frac{n+1}{n-1}} H^{\frac{m(n+1)}{2n}}$ Brooke and Levy.

Poles.—To determine the position of the poles we have the following formulæ:—

$$\tan \phi = \pm m \sin \beta \cos (\alpha + \beta) \operatorname{cosec} \alpha$$

$$\cot \psi = \sin \phi \operatorname{cosec} (45 + \phi) \sin 45 \tan (\alpha + \beta)$$

$$\mu = \psi + \alpha + \beta - \psi \text{ and } \tan \lambda = n \sin \beta \tan \gamma \sec \psi.$$

The positive or negative sign being used for $\tan \phi$, according as the hemipyramid is positive or negative.

Faces parallel to the following Pyramids of the Second Class have been observed in nature.

The form 1 2 $\frac{1}{2}$; $\frac{1}{2}$ P 2 Naumann; 2 1 4 Miller; $D^1 D^3 H^{\frac{3}{8}}$ Brooke and Levy.

Sphene	$\lambda = 82° 16'$	$\mu = 55° 33'$

The form 1 2 1; P 2 Naumann; 2 1 2 Miller; $D^1 D^3 H^{\frac{3}{4}}$ Brooke and Levy.

Klaprothine	$\lambda = 67° 22'$	$\mu = 29° 25'$	Spodumene	$\lambda = 45° 33'$	$\mu = 49° 50'$
Miargyrite	$\lambda = 45° 5'$	$\mu = 40° 2'$	Wagnerite	$\lambda = 71° 24'$	$\mu = 63° 25'$
Realgar	$\lambda = 64° 59'$	$\mu = 73° 33'$			

Realgar has a cleavage parallel to this form.

The form $1\,2\,\frac{4}{3}$; $\frac{4}{3}$ P 2 Naumann; 4 2 3 Miller; $D^1 D^3 H^1$ Brooke and Levy.
Humite . . $\lambda = 52° 2'$ $\mu = 54° 29'$

The form 1 2 2; 2 P 2 Naumann; 2 1 1 Miller; $D^1 D^3 H^{\frac{3}{2}}$ Brooke and Levy.
Chessylite $\lambda = 68° 49'$ $\mu = 26° 9'$ Miargyrite $\lambda = 38° 36'$ $\mu = 25° 8'$
Epidote . $\lambda = 48° 21'$ $\mu = 34° 21'$ Mirabilite $\lambda = 59° 6'$ $\mu = 32° 26'$
Humite . $\lambda = 45° 53'$ $\mu = 40° 37'$

The form 1 2 4; 4 P 2 Naumann; 4 2 1 Miller; $D^1 D^3 H^3$ or $_3A$ Brooke and Levy.
Miargyrite . $\lambda = 35° 34'$ $\mu = 13° 4'$ | Realgar . . $\lambda = 54° 15'$ $\mu = 26° 7'$

The form $1\,\frac{7}{3}\,7$; 7 P $\frac{7}{3}$ Naumann; 7 3 1 Miller; $D^1 D^{\frac{5}{2}} H^5$ Brooke and Levy.
Miargyrite . $\lambda = 38° 56'$ $\mu = 7° 39'$

The form $1\,3\,\frac{3}{4}$; $\frac{3}{4}$ P 3 Naumann; 3 1 4 Miller; $D^1 D^2 H^{\frac{1}{2}}$ Brooke and Levy.
Wagnerite . $\lambda = 79° 35'$ $\mu = 73° 37'$

The form $1\,3\,\frac{3}{2}$; $\frac{3}{2}$ P 3 Naumann; 3 1 2 Miller; $D^1 D^2 H^1$ Brooke and Levy.
Freieslebenite $\lambda = 79° 55'$ $\mu = 22° 34'$

The form 1 3 2; 2 P 3 Naumann; 6 2 3 Miller; $D^1 D^2 H^{\frac{4}{3}}$ Brooke and Levy.
Humite . . $\lambda = 58° 1'$ $\mu = 40° 37'$

The form 1 3 3; 3 P 3 Naumann; 3 1 1 Miller; $D^1 D^2 H^2$ or $_2A$ Brooke and Levy.
Miargyrite . $\lambda = 47° 59'$ $\mu = 17° 38'$

The form 1 4 1; P 4 Naumann; 4 1 4 Miller; $D^1 D^{\frac{5}{3}} H^{\frac{2}{5}}$ Brooke and Levy.
Freieslebenite . $\lambda = 83° 3'$ $\mu = 31° 4'$

The form 1 4 2; 2 P 4 Naumann; 4 1 2 Miller; $D^1 D^{\frac{5}{3}} H^{\frac{4}{5}}$ Brooke and Levy.
Realgar . . $\lambda = 71° 19'$ $\mu = 44° 2'$

The form 1 4 4; 4 P 4 Naumann; 4 1 1 Miller; $D^1 D^{\frac{5}{3}} H^{\frac{8}{5}}$ Brooke and Levy.
Chessylite . $\lambda = 78° 16'$ $\mu = 14° 10'$

The form 1 5 5; 5 P 5 Naumann; 5 1 1 Miller; $D^1 D^{\frac{3}{2}} H^3$ Brooke and Levy.
Miargyrite . $\lambda = 60° 23'$ $\mu = 10° 34'$

The form 1 6 3; 3 P 6 Naumann; 6 1 2 Miller; $D^1 D^{\frac{7}{5}} H^{\frac{7}{4}}$ Brooke and Levy.
Realgar . . $\lambda = 76° 31'$ $\mu = 29° 25'$

The form $\bar{1}\,\frac{3}{2}\,1$; $-$P $\frac{3}{2}$ Naumann; $\bar{3}$ 2 1 Miller; $B^1 B^5 H^{\frac{6}{5}}$ Brooke and Levy.
Pharmacolite . $\lambda = 69° 38'$ $\mu = 148° 42'$ | Euclase . . $\lambda = 67° 10'$ $\mu = 99° 59'$

The form $\bar{1}$ 2 1; $-$ P 2 Naumann; $\bar{2}$ 1 2 Miller; $B^1 B^3 H^{\frac{3}{4}}$ Brooke and Levy.
Realgar . . $\lambda = 72° 33'$ $\mu = 139° 46'$

The form $\bar{1}$ 2 2; $-$2 P 2 Naumann; $\bar{2}$ 1 1 Miller; $B^1 B^3 H^{\frac{3}{2}}$ Brooke and Levy.
Bragationite . $\lambda = 59° 8'$ $\mu = 157° 20'$ | Lehmannite . $\lambda = 65° 49'$ $\mu = 128° 58'$

The form $\bar{1}$ 2 4; $-$4 P 2 Naumann; $\bar{4}$ 2 1 Miller; $B^1 B^3 H^3$ or A_3 Brooke and Levy.
Humite . . $\lambda = 46° 52'$ $\mu = 161° 0'$

The form $\bar{1}$ 3 1; $-$P 3 Naumann; $\bar{3}$ 1 3 Miller; $B^1 B^2 H^{\frac{2}{3}}$ Brooke and Levy.
Gypsum . . $\lambda = 67° 30'$ $\mu = 113° 46'$ | Miargyrite . $\lambda = 53° 10'$ $\mu = 131° 46'$

The form $\bar{1}$ 3 3; $-$ 3 P 3 Naumann; $\bar{3}$ 1 1 Miller; $B^1 B^2 H^2$ or A_2 Brooke and Levy.
Amphibole . $\lambda = 49° 52'$ $\mu = 106° 2'$ | Glauberite $\lambda = 68° 4'$ $\mu = 155° 25'$
Euclase . $\lambda = 78° 6'$ $\mu = 140° 20'$

The form $\bar{1}\ 6\ 1$; $-$ P 6 Naumann; $\bar{6}\ 1\ 6$ Miller; $B^1\ B^{\frac{7}{5}}\ H^{\frac{7}{12}}$ Brooke and Levy.
Miargyrite . $\lambda = 70°\ 30'$ $\mu = 131°\ 46'$

Derived Oblique Octahedron of the Third Class.—This octahedron may be drawn and its net described, by making CP_1 and CP'_1 (Fig. 325) m times the parameter CP (Fig. 326); where m may be any whole number or fraction, equal to, greater, or less than unity; and CG_1, CG_2 (Fig. 325) equal to n times the parameter CG (Fig. 326), where n may be any whole number, or fraction greater than unity.

Symbols.—The symbol for the positive hemipyramid of this octahedron is $n\ 1\ m$; (m P n) Naumann; $k\ h\ l$ Miller; $D^1\ D^{\frac{n+1}{n-1}}\ G^{\frac{m(n+1)}{2n}}$ Brooke and Levy. For the negative hemipyramid $\bar{n}\ 1\ m$; — (m P n) Naumann; $\bar{k}\ h\ l$ Miller; $B^1\ B^{\frac{n+1}{n-1}}\ G^{\frac{m(n+1)}{2n}}$ Brooke and Levy.

Poles.—To determine the position of the poles we have the following formulæ:—

$$\tan \phi = \pm \frac{m}{n} \sin \beta \cos (\alpha + \beta) \operatorname{cosec} \alpha$$

$$\cot \psi = \sin \phi \operatorname{cosec} (45 + \phi) \sin 45 \tan (\alpha + \beta)$$

$$\mu = \psi + \alpha + \beta - \psi \quad \text{and} \quad \tan \lambda = \frac{1}{n} \sin \beta \tan \gamma \sec \psi$$

The positive or negative sign being used for $\tan \phi$ according as the hemipyramid is positive or negative.

Faces parallel to the following Pyramids of the Third Class have been observed in nature.

The form $\frac{3}{2}\ 1\ \frac{3}{2}$; ($\frac{3}{2}$ P $\frac{3}{2}$) Naumann; 2 3 2 Miller; $D^1\ D^5\ G^{\frac{5}{4}}$ Brooke and Levy.
Realgar . . $\lambda = 35°\ 33'$ $\mu = 73°\ 33'$

The form $2\ 1\ \frac{2}{5}$; ($\frac{2}{5}$ P 2) Naumann; 1 2 5, Miller; $D^1\ D^3\ G^{\frac{3}{10}}$ Brooke and Levy.
Chessylite . . $\lambda = 71°\ 35'$ $\mu = 80°\ 32'$

The form $2\ 1\ \frac{2}{3}$; ($\frac{2}{3}$ P 2) Naumann; 1 2 3 Miller; $D^1\ D^3\ G^{\frac{1}{2}}$ Brooke and Levy.
Sphene . . . $\lambda = 68°\ 2'$ $\mu = 66°\ 52'$

The form $2\ 1\ \frac{4}{5}$; ($\frac{4}{5}$ P 2) Naumann; 2 4 5 Miller; $D^1\ D^3\ G^{\frac{3}{5}}$ Brooke and Levy.
Chessylite . . $\lambda = 56°\ 35'$ $\mu = 69°\ 29'$

The form 2 1 1; (P 2) Naumann; 1 2 2 Miller; $D^1\ D^3\ G^{\frac{3}{4}}$ Brooke and Levy.
Epidote . . $\lambda = 32°\ 23'$ $\mu = 89°\ 27'$ | Wagnerite . . $\lambda = 53°\ 2'$ $\mu = 35°\ 4'$

The form $2\ 1\ \frac{4}{3}$; ($\frac{4}{3}$ P 2) Naumann; 2 4 3 Miller; $D^1\ D^3\ G^1$ Brooke and Levy.
Chessylite . . $\lambda = 45°\ 29'$ $\mu = 56°\ 57'$

The form 2 1 2; (2 P 2) Naumann; 1 2 1 Miller; $D^1\ D^3\ G^{\frac{3}{2}}$ Brooke and Levy.
Barytocalcite $\lambda = 34°\ 0'$ $\mu = 61°\ 0'$ | Monazite . $\lambda = 40°\ 32'$ $\mu = 39°\ 20'$
Freieslebenite $\lambda = 76°\ 18'$ $\mu = 31°\ 41'$ | Natron . $\lambda = 39°\ 50'$ $\mu = 58°\ 52'$

The form 2 1 4; (4 P 2) Naumann; 2 4 1 Miller; $D^1\ D^3\ G^3$ or E_3 Brooke and Levy.
Chessylite . . $\lambda = 32°\ 50'$ $\mu = 26°\ 9'$ | Felspar . . $\lambda = 37°\ 35'$ $\mu = 35°\ 45'$

The form $3\ 1\ \frac{3}{4}$; ($\frac{3}{4}$ P 3) Naumann; 1 3 4 Miller; $D^1\ D^2\ G^{\frac{1}{2}}$ Brooke and Levy.
Chessylite . . $\lambda = 57°\ 12'$ $\mu = 77°\ 41'$

The form $3\ 1\ \frac{3}{2}$; ($\frac{3}{2}$ P 3) Naumann; 1 3 2 Miller; $D^1\ D^2\ G^1$ Brooke and Levy.
Wheweilite . $\lambda = 28°\ 41'$ $\mu = 62°\ 49'$

The form 3 1 3; (3 P 3) Naumann; 1 3 1 Miller; $D^1\ D^3\ G^3$ or E_3 Brooke and Levy.

Amphibole .	$\lambda = 55° 46'$	$\mu = 50° 35'$	Felspar	$\lambda = 33° 20'$	$\mu = 63° 48'$
Augite .	$\lambda = 36° 26'$	$\mu = 49° 50'$	Gypsum	$\lambda = 45° 39'$	$\mu = 52° 16'$
Euclase .	$\lambda = 53° 0'$	$\mu = 49° 17'$			

The form 4 1 4; (4 P 4) Naumann; 1 4 1 Miller; $D^1\ D^{\frac{5}{3}}\ G^{\frac{5}{3}}$ Brooke and Levy.

Sphene . . $\lambda = 33° 52'$ $\mu = 34° 27'$

The form 5 1 $\frac{5}{2}$; ($\frac{5}{2}$ P 5) Naumann; 1 5 2 Miller; $D^1\ D^{\frac{3}{2}}\ G^{\frac{3}{2}}$ or $E_{\frac{3}{2}}$ Brooke and Levy.

Augite . . $\lambda = 37° 49'$ $\mu = 60° 29'$

The form 6 1 2; (2 P 6) Naumann; 1 6 3 Miller; $D^1\ D^{\frac{7}{5}}\ G^{\frac{7}{5}}$ Brooke and Levy.

Sphene . . $\lambda = 39° 34'$ $\mu = 66° 52'$

The form $\overline{\tfrac{4}{3}}$ 1 4; — (4 P $\frac{4}{3}$) Naumann; $\bar{3}$ 4 1 Miller; $B^1\ B^7\ G^{\frac{7}{2}}$ Brooke and Levy.

Euclase . . $\lambda = 49° 52'$ $\mu = 140° 20'$

The form $\bar{2}$ 1 1; — (P 2) Naumann; $\bar{1}$ 2 2 Miller; $B^1\ B^3\ G^{\frac{3}{4}}$ Brooke and Levy.

Wagnerite . $\lambda = 59° 30'$ $\mu = 126° 32'$ | Lunnite . . $\lambda = 56° 58'$ $\mu = 103° 26'$

The form $\bar{2}$ 1 $\frac{4}{3}$; — ($\frac{4}{3}$ P 2) Naumann; $\bar{2}$ 4 3 Miller; $B^1\ B^3\ G^1$ Brooke and Levy.

Chessylite . $\lambda = 46° 36'$ $\mu = 126° 12'$

The form $\bar{2}$ 1 2; — (2 P 2) Naumann; $\bar{1}$ 2 1 Miller; $B^1\ B^3\ G^{\frac{3}{2}}$ Brooke and Levy.

Chessylite .	$\lambda = 39° 55'$	$\mu = 137° 18'$	Gypsum .	$\lambda = 52° 50'$	$\lambda = 113° 46'$
Euclase .	$\lambda = 56° 52'$	$\mu = 99° 59'$	Sphene .	$\lambda = 55° 27'$	$\lambda = 148° 28'$

The form $\bar{2}$ 1 $\frac{8}{3}$; — ($\frac{8}{3}$ P 2) Naumann; $\bar{4}$ 8 3 Miller, $B^1\ B^3\ G^2$ Brooke and Levy.

Augite . . $\lambda = 34° 51'$ $\mu = 114° 31'$

The form $\bar{2}$ 1 4; — (4 P 2) Naumann; $\bar{2}$ 4 1 Miller; $B^1\ B^3\ G^3$ or ${}_3E$ Brooke and Levy.

Felspar . . $\lambda = 49° 10'$ $\mu = 157° 7'$

The form $\bar{3}$ 1 3; — (3 P 3) Naumann; 1 3 1 Miller; $B^1\ B^3\ G^2$ or ${}_2E$ Brooke and Levy.

Amphibole	$\lambda = 49° 45'$	$\mu = 106° 2'$	Mica .	: $31° 30'$	$\mu = 150° 27'$
Gypsum .	$\lambda = 41° 19'$	$\mu = 113° 46'$			

The combinations of this system are so like those of the Prismatic, that we need not give any examples of them.

SIXTH SYSTEM—ANORTHIC, OR DOUBLY OBLIQUE.

This system is called the *anorthic* from the want of symmetry of its forms; and the *doubly oblique* because its forms may be derived from the *doubly oblique prism*, and *doubly oblique octahedron*. It has also been called the *Triclinohedric*, *Anorthotype*, *Tetarto-prismatic*, *Tetarto-rhombic*, and the *One-and-one-membered* system.

To this system all forms may be referred which cannot be placed under any of the preceding systems.

Only two forms belong to the *anorthic system*: the *doubly oblique prism*, and the *doubly oblique octahedron* or *pyramid*.

Alphabetical list of Minerals belonging to the Anorthic or Doubly Oblique System, with the Angular Elements from which their typical forms and axes may be derived. Blanks are left in the cases where the Angular Elements have not been determined.

	α	β	γ	A	B	C	δ	ε
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
Albite (cleavelandite: Tetarto-prismatic felspar)	94 46	63 26	93 8	93 36	63 36	91 18	58 26	41 35
Axinite	91 49	82 2	102 36	90 5	82 14	102 30	52 0	51 21
Babingtonite	93 36	86 47	112 39	92 34	88 0	112 30	39 18	23 49
Blue vitriol (sulphate of copper)	73 12	67 8	82 56	70 22	65 4	100 41	28 4	27 16
Christianite (anorthite)	93 11	63 46	88 41	91 12	63 38	86 58	57 31	40 55
Kyanite (disthene)	—	—	—	—	—	—	—	—
Labradorite (Labrador felspar)	94 46	63 26	93 8	93 36	63 36	91 18	58 26	41 35
Latrobite	—	—	—	—	—	—	—	—
Leucophane	—	—	—	—	—	—	—	—
Oligoclase	94 46	63 26	93 8	93 36	63 36	91 18	58 26	41 35
Sassoline (native boracic acid)	92 32	104 18	89 42	92 32	104 18	90 20	29 59	27 51

Parameters and Axes.—In the anorthic system the three parameters are unequal, and no two axes are inclined to each other at right angles. By means of the angular elements α, β, A, δ and ε we may determine the lengths of the parameters and the inclination of the axes.

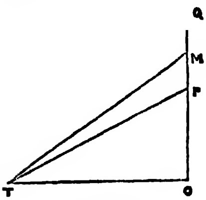


Fig. 342.

To determine the Lengths of the Parameters.—Take a straight line OT (Fig. 342) of any convenient length to represent one of the parameters; this will be the arbitrary unit of the system. Through one of its extremities O, draw OQ perpendicular to OT; through T draw TM, making an angle δ; and TP making an angle ε with OT; let TM and TP cut OQ in M and P.

Then OM and OP will represent the lengths of the other two parameters.

To represent the Inclination of the Axes in Perspective.—Draw a straight line XOX′ (Fig. 343), and through O a point in it the line OZ perpendicular to XX′, and the line OY making with OX′ an angle of about 30° with OX′. Along OX take OT_1 equal OT (Fig. 342).

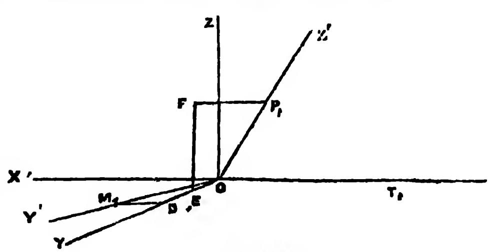


Fig. 343.

Then (Fig. 344) draw a line ABC, and through B a point in it draw BD making the angle γ with AB, take BD equal to OM (Fig. 342), and through D draw DF perpendicular to AC. In OY (Fig. 343) take OD equal to half of DF (Fig. 344), and through D (Fig. 343) draw DM_1 parallel to OX and equal to BF (Fig. 344). Join OM_1 and produce it to OY′.

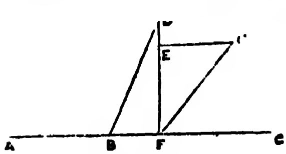


Fig. 344.

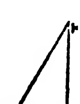


Fig. 345.

Now (Fig. 344) draw FG making the angle β with FC, take FG equal to OP (Fig. 342), and through G draw GE perpendicular to DF.

Draw HK and KL (Fig. 345) at right angles to each other, take KH equal

to FE (Fig. 344); through H draw HL, making the angle 90° — A with HK and meeting KL in L.

In OY (Fig. 343) take OE equal to half of LK (Fig. 345), through E draw EF parallel to OZ and equal to HK (Fig. 345).

Through F draw FP_1 parallel to OX and equal to EG (Fig. 336); join OP_1 and produce it to any point Z'.

Then OX, OY′ and OZ′ will represent the direction of the axes for any substance whose angular elements α, β and A are given (page 458), and OT, OM, and OP will represent the magnitude of its parameters, depending upon the angles δ and ϵ.

Doubly Oblique Prism—First Order.—The doubly oblique prism is a solid bounded by six faces, which are all oblique parallelograms, and equal to each other

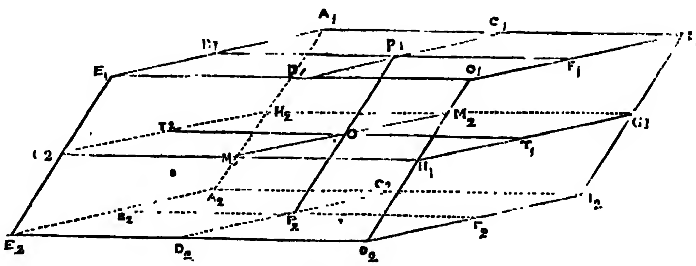


Fig. 346.

only in pairs. The face $A_1\ E_1\ O_1\ I_1$ (Fig. 346) being equal and parallel to the face $A_2\ E_2\ O_2\ I_2$; the face $O_1\ I_1\ I_2\ O_2$ equal and parallel to $E_1\ A_1\ A_2\ E_2$; and the face $A_1\ I_1\ I_2\ A_2$ equal and parallel to $E_1\ O_1\ O_2\ E_2$.

This prism, like the oblique prism, is now generally regarded as a combination of three open forms, each consisting of a pair of parallel faces.

Symbols.—The *basal pinacoids* $O_1\ I_1\ A_1\ E_1$, $O_2\ I_2\ A_2\ E_2$ cut the axis $P_1\ P_2$ at the extremities of the parameters OP_1, OP_2, and are parallel to the axes $M_1\ M_2$, $T_1\ T_2$; the symbol which expresses this relation is $\infty\ \infty\ 1$; Naumann's symbol is OP; Miller's 0 0 1; Brooke and Levy's P.

The *macro-pinacoids* $O_1\ E_1\ E_2\ O_2$ and $A_1\ I_1\ I_2\ A_2$ cut the axis $M_1\ M_2$ at the extremities of the parameters OM_1, OM_2, and are parallel to the axes $P_1\ P_2$ and $T_1\ T_2$. Their symbol is $\infty\ 1\ \infty$; $\infty\ \bar{P}\ \infty$ Naumann; 0 1 0 Miller; and M Brooke and Levy.

The *brachy-pinacoids* $O_1\ I_1\ I_2\ O_2$ and $E_1\ A_1\ A_2\ E_2$ cut the axis $T_1\ T_2$ at the extremities of the parameters OT_1, OT_2, and are parallel to the axes $P_1\ P_2$, $M_1\ M_2$. Their symbol is $1\ \infty\ \infty$; $\infty\ \breve{P}\ \infty$ Naumann; 1 0 0 Miller; T Brooke and Levy.

To draw the Doubly Oblique Prism, First Order.—Prick off from Fig. 343 the points O, P_1, M_1 and T_1. Join M_1 O and produce it to M_2, making OM_2 equal OM_1.

Join P_1 O and produce to P_2, making OP_2 equal to OP_1. And join T_1 O, produce it to T_2, making OT_2 equal to OT_1.

Through M_1 and M_2 draw $H_1\ G_2$ and $G_1\ H_2$ parallel to $T_1\ T_2$, making $M_1\ H_1$, $M_1\ G_2$, $M_2\ G_1$, and $M_2\ H_2$ each equal to OT_1.

Join $H_1\ G_1$ and $H_2\ G_2$. Through H_1, G_1, H_2, and G_2 draw $O_1\ O_2$, $I_1\ I_2$, $A_1\ A_2$ and $E_1\ E_2$ parallel to $P_1\ P_2$.

Make $O_1\ H_1$, $O_2\ H_1$, $G_1\ I_1$, $G_1\ I_2$, $H_2\ A_1$, $H_2\ A_2$, $G_2\ E_1$ and $G_2\ E_2$ each equal to OP_1.

Join $O_1\ I_1$, $I_1\ A_1$, $A_1\ E_1$, $E_1\ O_1$, $O_2\ I_2$, $I_2\ A_2$, $A_2\ E_2$ and $O_2\ E_2$.

To describe a Net for the Doubly Oblique Prism.—Draw CD (Fig. 347) equal twice OT (Fig. 342) and DB, making the angle γ with CD, and equal to twice OM (Fig. 342).

Through C draw CA parallel to BD, and through B, BA parallel to CD meeting in A.

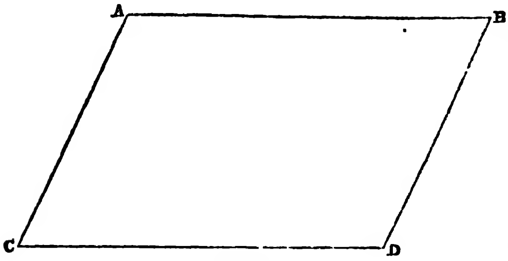


Fig. 347.

Draw GH (Fig. 348) equal twice OT (Fig. 342) and GE, making the angle β with GH, and equal to twice OP (Fig. 342).

Through E draw EF parallel to GH and through H, HF parallel to EG meetin in F.

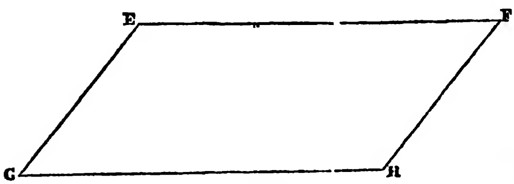


Fig. 348.

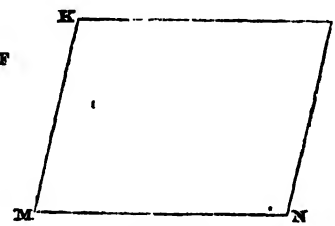


Fig. 349.

Also draw MN (Fig. 349) equal to twice OM (Fig. 342) and MK, making the angle α with MN and equal to twice OP (Fig. 342).

Through K draw KL parallel to MN and through N, NL parallel to MK meeting in L.

Then arrange six parallelograms, equal and similar in pairs to the three parallelograms (Figs. 347, 348, and 349), as in Fig. 350, and the net will be described.

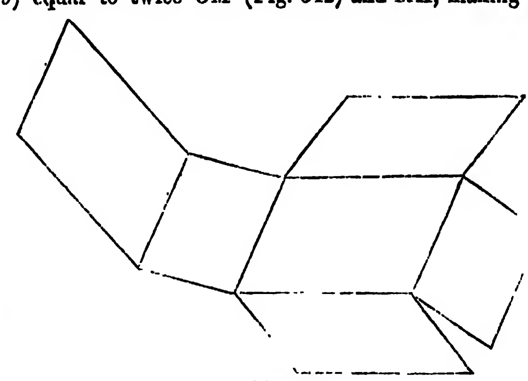


Fig. 350.

Crystals of the following minerals have Faces parallel to the Basal Pinacoids ∞ ∞ 1; O P *Naumann*; 0 0 1 *Miller*; P *Brooke and Levy*. *The north and south poles of the Sphere of Projection may be considered the poles of the two faces of the Basal Pinacoids.*

Albite	Babingtonite	Christianite	Oligoclase
Axinite	Blue Vitriol	Labradorite	Sassoline

The following present Cleavages parallel to this form.

Albite	*Babingtonite*	*Labradorite*	*Sassoline*
Axinite	*Christianite*	*Oligoclase*	

Crystals of the following minerals have Faces parallel to the Macro-pinacoids ∞ 1 ∞; ∞ $\bar{\mathrm{P}}$ ∞ *Naumann;* 0 1 0 *Miller;* M *Brooke and Levy. The angles will determine the position of one of the poles.*

Albite	North	Polar distance	86° 24′	Longitude	West	90° 0′
Axinite	North	" "	89° 55′	"	"	90° 0′
Babingtonite	North	" "	87° 26′	"	"	90° 0′
Blue Vitriol	South	" "	70° 22′	"	"	90° 0′
Christianite	North	" "	85° 48′	"	"	90° 0′
Labradorite	North	" "	86° 24′	"	"	90° 0′
Oligoclase	North	" "	86° 24′	"	"	90° 0′

The following present Cleavages parallel to this form.

Albite Axinite *Christianite* Labradorite Oligoclase.

Crystals of the following minerals have Faces parallel to the Brachy-pinacoids 1 ∞ ∞;

∞ $\breve{\mathrm{P}}$ ∞ *Naumann;* 1 0 0 *Miller;* T *Brooke and Levy.*

Axinite	South	Polar distance	82° 14′	Longitude	West	12° 36′
Babingtonite	South	" "	88° 0′	"	West	22° 39′
Blue Vitriol	South	" "	65° 4′	"	East	7° 4′
Sassoline	North	" "	75° 42′	"	East	0° 18′

Axinite and Babingtonite have imperfect cleavages parallel to this form.

Doubly Oblique Rhombic Prism, Second Order.—If we bisect the edges $O_1\,I_1$ (Fig. 346) $O_2\,I_2$ in F_1 and F_2, the edges $A_1\,E_1$ and $A_2\,E_2$ in B_1 and B_2; the edges $O_1\,E_1$, $O_2\,E_2$ in D_1 and D_2; and the edges $A_1\,I_1$, $A_2\,I_2$ in C_1 and C_2: and then prick off the points B_1, D_1, F_1, C_1, B_2, D_2, F_2, C_2, and join them as in Fig. 350, we shall derive from the doubly oblique prism (Fig. 346) another doubly oblique prism, similar in form, but differing in position and magnitude with respect to the oblique axes of the anorthic system.

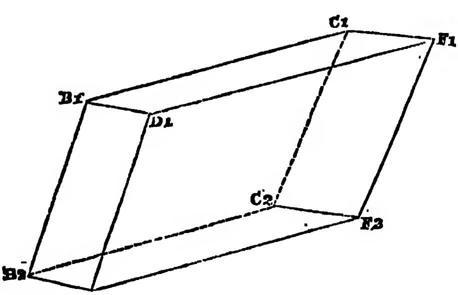


Fig. 351.

This prism is generally considered as the combination of three forms, each consisting of a pair of parallel faces.

$B_1\,D_1\,C_1\,F_1$ and $B_2\,D_2\,C_2\,F_2$ are regarded as faces of the basal pinacoid.

Symbols.—The form whose faces are $D_1\,F_1\,F_2\,D_2$ and $B_1\,C_1\,C_2\,B_2$ cuts each of the axes $M_1\,M_2$, $T_1\,T_2$ at the extremities of their parameters, and is parallel to the third axis $P_1\,P_2$. Its symbol is 1 1 ∞′; ∞ P′ Naumann; 1 1 0 Miller; H^1 Brooke and Levy.

The form whose faces are $B_1\,D_1\,B_2\,D_2$ and $C_1\,F_1\,C_2\,F_2$ cuts each of the axes $M_1\,M_2$, $T_1\,T_2$ (Fig. 346) at the extremities of their parameters, and is parallel to the third axis $P_1\,P_2$. Its symbol is $\bar{1}$ 1 ∞ ; ∞ ′P Naumann; $\bar{1}$ 1 0 Miller; G Brooke and Levy.

The form 1 1 ∞ ; ∞ P¦ Naumann; 1 1 0 Miller; H¹ Brooke and Levy, occurs in

Albite	South	Polar distance	69° 9′	Longitude	West	33° 50′
Axinite	South	„ „	84° 29′	„	West	45° 41′
Blue Vitriol	South		62° 25′		West	60° 29′
Christianite	South		69° 3′		West	31° 33′
Labradorite	South		69° 9′		West	33° 50′
Oligoclase	South		69° 9′		West	33° 50′
Sassoline	North		80° 33′		West	59° 6′

Blue Vitriol, Labradorite, and Oligoclase have imperfect cleavages parallel to this form.

The form $\bar{1}$ 1 ∞; ∞¦P Naumann; $\bar{1}$ 1 0 Miller; G¹ Brooke and Levy.

Albite	North	Polar distance	64° 55′	Longitude	West	150° 44′
Axinite	North	„ „	83° 33′	„	West	150° 1′
Babingtonite	North	„ „	85° 54′	„	West	137° 49′
Blue Vitriol	South	„ „	83°. 8′	„	West	116° 24′
Christianite	North	„ „	65° 38′	„	West	146° 35′
Labradorite	North	„ „	64° 55′	„	West	150° 44′
Oligoclase	North	„ „	64° 55′	„	West	150° 44′
Sassoline	South	„ „	84° 57′	„	West	119° 55′

Albite and Blue Vitriol have cleavages parallel to this form.

Doubly Oblique Prisms derived from that of the Second Order.—By making OT_1 and OT_2 in Fig. 346 n times greater than the parameter OT (Fig. 342), where n is any whole number or fraction greater than unity, we may from Fig. 346, so altered, derive another prism of the second order composed of the basal pinacoids and two forms whose symbols will be

n 1 ∞ ; ∞ $\bar{\mathrm{P}}$¦ n Naumann; 1 n 0 Miller; H^n Brooke and Levy.

and $\bar{n}$ 1 ∞ ; ∞ '¦$\bar{\mathrm{P}}$ n Naumann; $\bar{1}$ n 0 Miller; G^n Brooke and Levy.

By making OM_1 and OM_2 (Fig. 346) n times greater than the parameter OM (Fig. 342), where n is any whole number or fraction greater than unity, we may from Fig. 346, so altered, derive a prism of the second order composed of the basal pinacoids and two forms whose symbols will be

1 n ∞ ; ∞ $\breve{\mathrm{P}}$¦ n Naumann; n 1 0 Miller; $\mathrm{H}^{\frac{1}{n}}$ Brooke and Levy.

and $\bar{1}$ n ∞ ; ∞ ¦$\breve{\mathrm{P}}$ n Naumann; $\bar{n}$ 1 0 Miller; $\mathrm{G}^{\frac{1}{n}}$ Brooke and Levy.

The form 3 1 0; ∞ $\bar{\mathrm{P}}$¦ 3 Naumann; 1 3 0 Miller; H³ Brooke and Levy.

Albite	South	Polar distance	79° 56′	Longitude	West	62° 15′
Christianite	„	„	80° 33′	„	„	62° 5′
Oligoclase	„	„	79° 56′	„	„	62° 15′

The form $\bar{3}$ 1 0; ∞ ¦$\bar{\mathrm{P}}$ 3 Naumann; $\bar{1}$ 3 0 Miller; G³ Brooke and Levy.

Albite	North	Polar distance	73° 21′	Longitude	West	119° 10′
Christianite	„	„	73° 42′	„	„	117° 21′
Oligoclase	„	„	73° 21′	„	„	119° 10′

The form 2 1 0; ∞'$\bar{\mathrm{P}}$¦ 2 Naumann; 1 2 0 Miller; H² Brooke and Levy.

Axinite, South Polar distance 86° 14′ Longitude West 61° 7′

The form 2 $\bar{1}$ 0; ∞ ¦P 2 Naumann; $\bar{1}$ 2 0 Miller; G² Brooke and Levy.

Blue Vitriol, South Polar distance 77° 47′ Longitude West 104° 22′

The form 1 2 0; ∞$\breve{\mathrm{P}}$¦ 2 Naumann; 2 1 0 Miller; $\mathrm{H}^{\frac{1}{2}}$ Brooke and Levy.

Babingtonite, North Polar distance 89° 35′ Longitude West 47° 10′

The form $\bar{1}$ 2 0; ∞ ¦$\breve{\mathrm{P}}$ 2 Naumann; $\bar{2}$ 1 0 Miller; $\mathrm{G}^{\frac{1}{2}}$ Brooke and Levy.

Blue Vitriol, North Polar distance 87° 24′ Longitude West 133° 5′

Doubly Oblique Prism, Third Order.—The doubly oblique prism of the third order may be drawn by pricking off the points D_1, C_1, H_1, G_1, D_2, C_2, H_2, and G_2 from Fig. 346, and joining them as in Fig. 352. It is similar in form, but differs both in magnitude and position, from that of the first order. It may be regarded as composed of three forms, each consisting of two parallel faces. $D_1\,H_1\,G_2\,D_2$ and $C_1\,G_1\,C_2\,H_2$ are the faces of the macro-pinacoid.

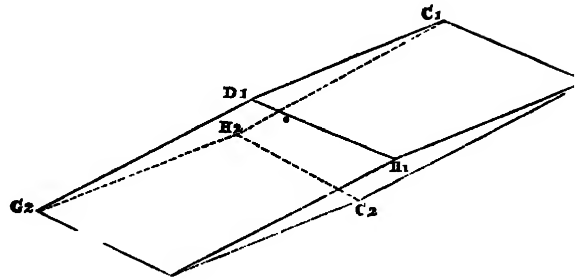


Fig. 352.

Symbols.—The faces of both the other forms cut the axes $P_1\,P_2$ (Fig. 346), $T_1\,T_2$ at the extremities of their parameters, and are parallel to the third axis $M_1\,M_2$.

The symbol for the form whose faces are $D_1\,C_1\,H_1\,G_1$ and $G_2\,H_2\,C_2\,D_2$ is $1\ \infty\ 1$; ${}_1\breve{P}^1\ \infty$ Naumann; 1 0 1 Miller; F^1 Brooke and Levy.

The symbol for the form whose faces are $D_1\,C_1\,H_2\,G_2$ and $H_1\,G_1\,C_2\,D_2$ is $\bar{1}\ \infty\ 1$; ${}^1\breve{P}_1\ \infty$ Naumann; 1 0 1 Miller; B^1 Brooke and Levy.

The form $1\ \infty\ 1$; ${}_1\breve{P}^1\ \infty$ Naumann; 1 0 1 Miller; F^1 Brooke and Levy, occurs in

Albite	North Polar distance	52° 37′	Longitude	West	3° 8′
Axinite	,, ,,	56° 55′		West	12° 36′
Blue Vitriol	,, ,,	29° 42′		East	7° 4′
Christianite	,, ,,	51° 33′		East	1° 19′
Oligoclase	,, ,,	52° 37′		West	3° 8′
Sassoline	,, ,,	24° 21′		East	0° 18′

Axinite has an imperfect cleavage parallel to this form.

The form $\bar{1}\ \infty\ 1$; ${}^1\breve{P}_1\ \infty$ Naumann; $\bar{1}$ 0 1 Miller; B^1 Brooke and Levy.

Blue Vitriol	North Polar distance	20° 27′	Longitude	East	18[illegible] 4′
Sassoline	,, ,,	30° 28′	,,	West	17[illegible] 42′

Derived Doubly Oblique Prisms of the Third Order.—By making OP_1 and OP_2 in Fig. 346, m times the parameter OP (Fig. 342), and from the figure so altered obtaining a prism of the third order, another series of doubly oblique prisms similar in form and position, but differing in magnitude from Fig. 352, may be derived. m may be any whole number or fraction greater or less than unity.

Symbols.—The symbol for the form whose faces are $D_1\,C_1\,H_1\,G_1$ and $G_2\,H_2\,C_2\,D_2$, is $1\ \infty\ m$; $m\ {}_1\breve{P}^1\ \infty$ Naumann; m 0 1 Miller; $F^{\frac{1}{m}}$ Brooke and Levy.

The symbol for the form whose faces are $D_1\,C_1\,H_2\,G_2$ and $H_1\,G_1\,C_2\,D_2$, is $\bar{1}\ \infty\ m$; $m\ {}^1\breve{P}_1\ \infty$ Naumann; $\bar{m}$ 0 1 Miller; $B^{\frac{1}{m}}$ Brooke and Levy.

The form $1\ \infty\ \frac{3}{2}$; $\frac{3}{2}\ {}_1\breve{P}^1\ \infty$ Naumann; 2 0 3 Miller; $F^{\frac{2}{3}}$ Brooke and Levy.

Christianite	North Polar distance	34° 48′	Longitude	East	1° 19′

The form $1\ \infty\ 2$; $2\ {}_1\breve{P}^1\ \infty$ Naumann; $2\ 0\ 1$ Miller; $F^{\frac{1}{2}}$ Brooke and Levy.

Albite	North Polar distance	82° 25′	Longitude West	3° 8′
Blue Vitriol	,, ,,	57° 16′	,, East	7° 4′
Christianite	,, ,,	81° 31′	,, East	1° 19′
Labradorite	,, ,,	82° 25′	,, West	3° 8′
Oligoclase	,, ,,	82° 25′	,, West	3° 8′

The form $\bar{1}\ \infty\ 2$; $2\ {}^1\breve{P}_1\ \infty$ Naumann; $\bar{2}\ 0\ 1$ Miller; $B^{\frac{1}{2}}$ Brooke and Levy.

Christianite North Polar distance 41° 14′ Longitude West 178° 41′

The form $1\ \infty\ 3$; $3_1\ \breve{P}^1\ \infty$ Naumann; $3\ 0\ 1$ Miller; $F^{\frac{1}{3}}$ Brooke and Levy.

Blue Vitriol North Polar distance 74° 42′ Longitude East 7° 4′

Doubly Oblique Prism of the Fourth Order.—By pricking off the points $F_1, F_2, B_1, B_2, H_1, H_2, G_1$ and G_2 from Fig. 346, and joining them as in Fig. 353, a doubly oblique prism of the fourth order may be derived, similar in form but differing in magnitude and position from that of the first order. This prism is a combination of three forms, each consisting of a pair of parallel faces. $F_1\ H_1\ F_2\ G_1$ and $B_1\ H_2\ B_2\ G_2$ are regarded as faces of the *brachy-pinacoids*, being parallel to the axes $P_1\ P_2$ and $M_1\ M_2$ (Fig. 346).

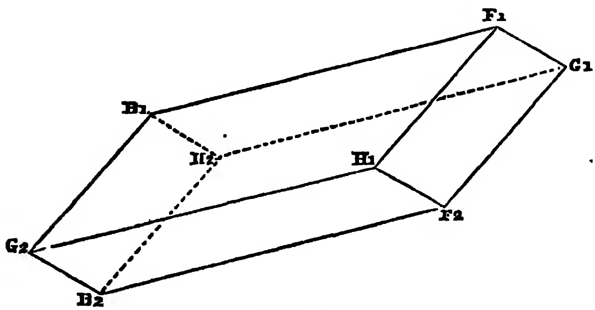


Fig. 353.

Symbols.—The faces of both the other forms cut the axes $P_1\ P_2$, $M_1\ M_2$, at the extremities of their parameters, and are parallel to the third axis $T_1\ T_2$ (Fig. 346).

The symbol for the form whose faces are $B_1\ F_1\ H_1\ G_2$ and $H_2\ G_1\ F_2\ B_2$ is $\infty\ 1\ 1$; ${}^1\bar{P}^1\ \infty$ Naumann; $0\ 1\ 1$ Miller; D^1 Brooke and Levy.

The symbol for the form whose faces are $B_1\ F_1\ G_1\ H_2$ and $G_2\ H_1\ F_2\ B_2$ is $\infty\ \bar{1}\ 1$; ${}_1\bar{P}_1\ \infty$ Naumann: $0\ \bar{1}\ 1$ Miller; C^1 Brooke and Levy.

The form $\infty\ 1\ 1$; ${}_1\bar{P}_1\ \infty$ Naumann; $0\ 1\ 1$ Miller; D^1 Brooke and Levy, occurs in—

Axinite	North polar distance	44° 43′	Longitude West	90° 0′
Babingtonite	,, ,,	29° 35′	,, ,,	90° 0′
Blue Vitriol	,, ,,	50° 28′	,, ,,	90° 0′

Axinite has a cleavage parallel to this form.

The form $\infty\ \bar{1}\ 1$; ${}_1\bar{P}_1\ \infty$ Naumann; $0\ \bar{1}\ 1$ Miller; C^1 Brooke and Levy.

Axinite South polar distance 44° 48′ Longitude West 90° 0′

Derived Doubly Oblique Prisms of the Fourth Order.—By making OP_1 and OP_2 (Fig. 346) m times the parameter OP (Fig. 342), where m may be any whole number or fraction greater or less than unity; and from Fig. 346, so altered, obtaining a prism of the fourth order, a series of prisms may be derived, similar in form and position, but differing in magnitude from Fig. 353.

Symbols.—The symbol for the form whose faces are $B_1\ F_1\ H_1\ G_2$ and $H_2\ G_1'\ F_2\ B_2$, is $\infty\ 1\ m$; $m\ {}_1\bar{P}_1\ \infty$ Naumann; $0\ m\ 1$ Miller; $D^{\frac{1}{m}}$ Brooke and Levy.

The symbol for the form whose faces are $B_1\ F_1\ G_1\ H_2$ and $G_2\ H_1\ F_2\ B_2$, is $\infty \bar{1}\ m$; $,P,\ \infty$ Naumann; $0\ \bar{m}\ 1$ Miller; $C^{\frac{1}{m}}$ Brooke and Levy.

$\frac{1}{2}\ '\bar{P}'\ \infty$ Naumann; 0 1 2 Miller; D^2 Brooke and Levy.

Axinite	North polar distance	26° 21′	Longitude West	90° 0′

The form $\infty\ 1\ 2$; $2\ '\bar{P}'\ \infty$ Naumann; 0 2 1 Miller; $D^{\frac{1}{2}}$ Brooke and Levy.

Albite	North polar distance	42° 34′	Longitude West	90° 0′
Christianite		42° 38′	" "	90° 0′
Oligoclase		42° 34′		90° 0′

The form $\infty\ 1\ 2$ $2\ ,\bar{P},\ \infty$ Naumann; $0\ \bar{2}\ 1$ Miller; $C^{\frac{1}{2}}$ Brooke and Levy.

Albite	North polar distance	46° 5′	Longitude East	90° 0′
Christianite		46° 47		90°
Oligoclase	"	" 46° 5′		90°

Doubly Oblique Octahedron.—The *doubly oblique octahedron*, or the *triclinohedric pyramid*, is a solid bounded by eight scalene triangles. These triangular faces are only equal and similar to each other in pairs; every face, such as $P_1\ M_1\ T_1$ (Fig. 354), having a similar and equal face, $P_2\ M_2\ T_2$, parallel to it. This solid may be regarded as a combination of four open forms, each form consisting of a pair of similar and parallel faces. These forms are called *tetarto-pyramids*, and can only appear in combination with other forms.

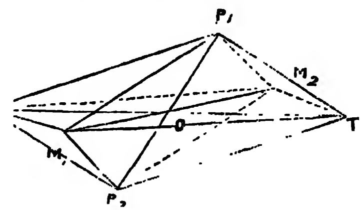


Fig. 354.

To draw the doubly oblique octahedron.—Prick off from Fig. 346 the points P_1, P_2, M_1, M_2, T_1 and T_2, and join them as in Fig. 354.

Axes.—The axes of the doubly oblique or anorthic system join the points $P_1\ P_2$, $M_1\ M_2$, and $T_1\ T_2$ (Fig. 354).

Symbols.—Every face of the doubly oblique octahedron cuts the three axes $P_1\ P_2$, $M_1\ M_2$, and $T_1\ T_2$ at the extremities of their parameters.

The symbol for the form whose faces are $P_1\ M_1\ T_1$ and $P_2\ M_2\ T_2$ is 1 1 1; P^1 Naumann; 1 1 1 Miller; O^1 Brooke and Levy.

The symbol for the form whose faces are $P_1\ M_1\ T_2$ and $P_2\ M_2\ T_1$ is $\bar{1}\ 1\ 1$; ^1P Naumann; $\bar{1}\ 1\ 1$ Miller; E^1 Brooke and Levy.

The symbol for the form whose faces are $P_1\ M_2\ T_2$ and $P_2\ M_1\ T_1$ is $1\ 1\ \bar{1}$; P_1 Naumann; $1\ 1\ \bar{1}$ Miller; A^1 Brooke and Levy.

The symbol for the form whose faces are $P_1\ M_2\ T_1$ and $P_2\ M_1\ T_2$ is $1\ \bar{1}\ 1$ $_1P$ Naumann; $1\ \bar{1}\ 1$ Miller; I^1 Brooke and Levy.

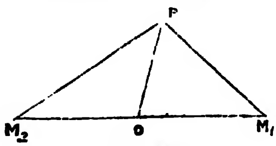


Fig. 355.

To describe a Net for the Doubly Oblique Octahedron.—Let α, β, and γ be the three angular elements given under those letters for a particular substance (page 458), whose octahedron is to be constructed.

Draw two lines OM_1, OP_1 (Fig. 355), making the angle α, with each other, produce OM_1 to M_2, make OM_1, OM_2 each equal to the parameter OM (Fig. 342) constructed for the particular substance, and OP_1 equal to the parameter OP (Fig. 342). Join $P_1\ M_1$ and $P_1\ M_2$.

Draw OP_1, OT_1 (Fig. 356), making the angle β with each other, produce OT_1 to T_2, make OT_1 and OT_2 equal to OT (Fig. 342), and OP_1 equal to OP (Fig. 342). Join $P_1\ T_1$ and $P_1\ T_2$.

Fig. 356. Fig. 357.

Also draw OT_1 and OM_1 (Fig. 357), making the angle γ with each other, produce OT_1 to T_2, make OT_1 and OT_2 equal to OT (Fig. 342), and OM_1 equal to OM (Fig. 342). Join $M_1\ T_1$ and $M_1\ T_2$.

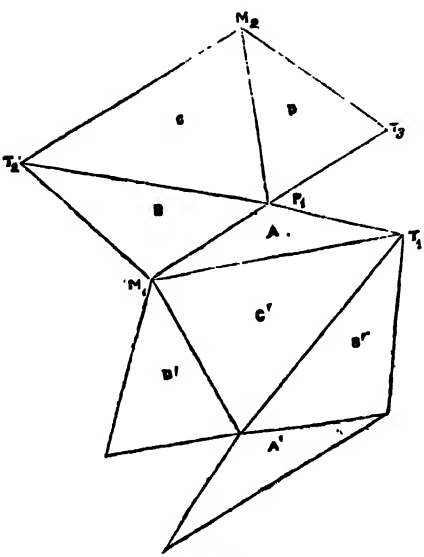


Fig. 358.

Then Fig. 358, draw $M_1\ T_1$ equal to $M_1\ T_1$ (Fig. 357), on it construct the triangle $M_1\ P_1\ T_1$ having its side $M_1\ P_1$ equal $M_1\ P_1$ (Fig. 355), and the remaining side $P_1\ T_1$ equal $P_1\ T_1$ (Fig. 356).

On $P_1\ M_1$ construct the triangle $P_1\ T_2\ M_1$, having $M_1\ T_2$ equal $M_1\ T_2$ (Fig. 357) and $P_1\ T_2$ equal to $P_1\ T_2$ (Fig. 356).

On $P_1\ T_2$ construct the triangle $P_1\ T_2\ M_2$ having $T_2\ M_2$ equal $T_1\ M_1$ (Fig. 357) and $P_1\ M_2$ equal $P_1\ M_2$ (Fig. 355).

On $P_1\ M_2$ construct the triangle $P_1\ M_2\ T_3$ having $M_2\ T_3$ equal $M_1\ T_2$ (Fig. 357) and $P_1\ T_3$ equal $P_1\ T_1$ (Fig. 356).

Then construct four other triangles equal and similar to each of these, and arrange them as in Fig. 358, and the net will be described.

The form 1 1 1; P[1] Naumann; 1 1 1 Miller; O[1] Brooke and Levy, has been observed in

Albite	North Polar distance		54° 44′	Longitude West		33° 50′
Axinite	„	„	64° 57′	„	„	45° 41′
Christianite	„	„	54° 22′	„	„	31° 33′
Oligoclase	„	„	54° 41′	„	„	33° 50′
Sassoline	„	„	41° 6′	„	„	59° 6′

The form $\bar{1}$ 1 1; [1]P Naumann; $\bar{1}$ 1 1 Miller; E[1] Brooke and Levy.

Axinite	North Polar distance		50° 36′	Longitude West		150° 1′
Blue Vitriol	„	„	48° 51′	„	„	116° 24′
Christianite	„	„	45° 14′	„	„	146° 35′
Sassoline	„	„	48° 0′	„	„	119° 55′

The form 1 1 $\bar{1}$; P_1 Naumann; 1 1 $\bar{1}$ Miller; A[1] Brooke and Levy.

Sassoline	North Polar distance	50° 52′	Longitude East	120° 54′

The form $1\ \bar{1}\ 1$; ${}_1P$ Naumann ; $1\ \bar{1}\ 1$ Miller ; I^1 Brooke and Levy.

Albite	North Polar distance	57° 37′	Longitude	East	29° 16′
Axinite	South „ „	60° 0′	„	West	150° 1′
Christianite	North „ „	58° 10′	„	East	33° 25′
Oligoclase	North „ „	57° 37′	„	East	29° 16′
Sassoline	North „ „	42° 51′	„	East	60° 5′

Angular Elements of the Anorthic System.—Five of the angular elements given in page 458 are necessary for the construction of any of the forms of the anorthic system ; α is the inclination of the axis OP_1 (Fig. 340) to OM_1, β of the axis OP_1 to OT_1, and γ of the axis OM_1 to OT_1 ; A is the inclination of the plane $P_1\,OT_1$ to the plane $M_1\,OT_1$; B is the inclination of the plane $P_1\,OM_1$ to the plane $M_1\,OT_1$; and c is the inclination of the plane $P_1\,OM_1$ to the plane $P_1\,OT_1$; the remaining elements δ and ϵ depend upon the ratios which the unequal parameters OP_1, OM_1 and OT_1 bear to each other.

Derived Doubly Oblique Octahedrons.—By making OP_1 and OP_2 equal to m times the parameter OP (Fig. 342) where m may be any whole number or fraction greater, equal to, or less than unity ; and OT_1 and OT_2 equal to n times the parameter OT (Fig. 342), where n is any whole number or fraction greater than unity, we may from Fig. 342 so altered derive a series of doubly oblique octahedrons, whose general symbol will be $n\ 1\ m$. By making OM_1 and OM_2 equal to n times OM (Fig. 342) instead of OT_1 n times OT_1, we may obtain another series of octahedrons whose general symbol will be $1\ n\ m$.

Symbols for the Forms composing the Derived Octahedrons.

The symbols for the form $1\ 1\ m$ are $m\ P^1$ Naumann ; $m\ m\ 1$ Miller ; O^m Brooke and Levy.

For the form $\bar{1}\ 1\ m$, $m\ {}^1P$ Naumann ; $\bar{m}\ m\ 1$ Miller ; E^m Brooke and Levy.

For the form $1\ \bar{1}\ m$; $m\ {}_1P$ Naumann ; $m\ m\ 1$ Miller ; I^m Brooke and Levy.

For the form $1\ 1\ \bar{m}$; $m\ P_1$ Naumann ; $m\ m\ 1$ Miller ; A^m Brooke and Levy.

For the form $1\ n\ 1$; $\breve{P}_1\ n$ Naumann ; $n\ 1\ n$ Miller ; ${}_nO$ Brooke and Levy.

For the form $\bar{1}\ n\ 1$ ${}^1\breve{P}\ n$ Naumann ; $\bar{n}\ 1\ n$ Miller ; ${}_nE$ Brooke and Levy.

For the form $1\ \bar{n}\ 1$ ${}_1\breve{P}\ n$ Naumann ; $n\ \bar{1}\ n$ Miller ; ${}_nI$ Brooke and Levy.

For the form $1\ n\ \bar{1}$ $\breve{P}_1\ n$ Naumann ; $n\ 1\ \bar{n}$ Miller ; ${}_nA$ Brooke and Levy.

For the form $n\ 1\ 1$ $\bar{P}^1\ n$ Naumann ; $1\ n\ n$ Miller ; O_n Brooke and Levy.

For the form $\bar{n}\ 1\ 1$ ${}^1\bar{P}\ n$ Naumann ; $\bar{1}\ n\ n$ Miller ; E_n Brooke and Levy.

For the form $n\ \bar{1}\ 1$ ${}_1\bar{P}\ n$ Naumann ; $1\ \bar{n}\ n$ Miller ; I_n Brooke and Levy.

For the form $n\ 1\ 1$ $P_1\ n$ Naumann ; $1\ n\ \bar{n}$ Miller ; A_n Brooke and Levy.

For the form $1\ n\ m$ $m\ \breve{P}^1\ n$ Naumann ; $h\ k\ l$ Miller ; $D^{\frac{1}{h}}\ F^{\frac{1}{k}}\ H^{\frac{1}{l}}$ Brooke and Levy.

For the form $\bar{1}\ n\ m$ $m\ {}^1\breve{P}\ n$ Naumann ; $\bar{h}\ k\ l$ Miller ; $B^{\frac{1}{h}}\ D^{\frac{1}{k}}\ G^{\frac{1}{l}}$ Brooke and Levy.

For the form $1\ \bar{n}\ m$ $m\ {}_1\breve{P}\ n$ Naumann ; $h\ k\ l$ Miller ; $F^{\frac{1}{h}}\ C^{\frac{1}{k}}\ G^{\frac{1}{l}}$ Brooke and Levy.

For the form $1\ n\ \bar{m}$ $m\ \breve{P}_1\ n$ Naumann ; $h\ k\ \bar{l}$ Miller ; $C^{\frac{1}{h}}\ B^{\frac{1}{k}}\ H^{\frac{1}{l}}$ Brooke and Levy.

For the form $n\ 1\ m$ $m\ \bar{P}^1\ n$ Naumann ; $h\ k\ l$ Miller ; $D^{\frac{1}{h}}\ F^{\frac{1}{k}}\ H^{\frac{1}{l}}$ Brooke and Levy.

For the form $\bar{n}\ 1\ m$; $m\ {}^{1}\bar{P}\ n$ Naumann; $\bar{h}\ k\ l$ Miller; $B^{h}\ D^{\bar{k}}\ G^{\bar{l}}$ Brooke and Levy.

For the form $n\ \bar{1}\ m$; $m\ {}_{1}\bar{P}\ n$ Naumann; $h\ \bar{k}\ l$ Miller; $F^{\frac{1}{h}}\ C^{\frac{1}{k}}\ G^{\frac{1}{\bar{l}}}$ Brooke and Levy.

For the form $n\ 1\ \bar{m}$; $m\ \bar{P}_{1}\ n$ Naumann; $h\ k\ \bar{l}$ Miller; $C^{\frac{1}{\bar{h}}}\ B^{\frac{1}{k}}\ H^{\frac{1}{\bar{l}}}$ Brooke and Levy.

The relation between the symbols $h\ k\ l$, and $1\ n\ m$, is that the former are the numerators of the reciprocals of the latter reduced to a common denominator.

The form $1\ 1\ \frac{1}{2}$; $\frac{1}{2}\ P^{1}$ Naumann; $1\ 1\ 2$ Miller; $O^{\frac{1}{2}}$ Brooke and Levy occurs in

Albite	North Polar distance	29° 50′	Longitude West	33° 50′

The form $1\ \bar{1}\ \frac{1}{2}$; $\frac{1}{2}\ {}_{1}P$ Naumann; $1\ \bar{1}\ 2$ Miller; $I^{\frac{1}{2}}$ Brooke and Levy.

Albite	North Polar distance	29° 55′	Longitude East	29° 16′
Axinite	South „ „	38° 4′	„ West	150° 1′

The form $1\ \bar{1}\ 2$; $2\ {}_{1}P$ Naumann; $2\ \bar{2}\ 1$ Miller; I^{2} Brooke and Levy.

Christianite	North Polar distance	85° 7′	Longitude East	33° 25′
Oligoclase	South „ „	85° 17′	„ „	29° 16′

The form $1\ 3\ 3$; $3\ \breve{\bar{P}}{}^{1}\ 3$ Naumann; $3\ 1\ 1$ Miller; $D^{\frac{1}{3}}\ F^{1}\ H^{1}$ Brooke and Levy.

Blue Vitriol	North Polar distance	86° 23′	Longitude West	20° 51′

The form $\bar{1}\ 2\ 2$; $2\ {}^{1}\breve{P}\ 2$ Naumann; $\bar{2}\ 1\ 1$ Miller, $B^{\frac{1}{2}}\ D^{1}\ G^{1}$ Brooke and Levy.

Blue Vitriol	North Polar distance	51° 1′	Longitude West	133° 5′

The form $1\ \bar{2}\ 2$; $2\ {}_{1}\breve{P}\ 2$ Naumann; $2\ \bar{1}\ 1$ Miller; $F^{\frac{1}{2}}\ C^{1}\ G^{1}$ Brooke and Levy.

Axinite	South Polar distance	75° 27′	Longitude West	169° 59′

The form $2\ 1\ 4$; $4\ \bar{P}^{1}\ 2$ Naumann; $2\ 4\ 1$ Miller; $D^{\frac{1}{2}}\ F^{\frac{1}{4}}\ H^{1}$ Brooke and Levy.

Christianite	North Polar distance	81° 28′	Longitude West	51° 21′

The form $2\ \bar{1}\ 4$; $4\ {}_{1}\bar{P}\ 2$ Naumann; $2\ \bar{4}\ 1$ Miller; $F^{\frac{1}{2}}\ C^{\frac{1}{4}}\ G^{1}$ Brooke and Levy.

Christianite	North Polar distance	88° 4′	Longitude East	55° 22′

The form $2\ 1\ 2$; $2\ \bar{P}^{1}\ 2$ Naumann; $1\ 2\ 1$ Miller; $D^{1}\ F^{\frac{1}{2}}\ H^{1}$ Brooke and Levy.

Axinite	North Polar distance	72° 9′	Longitude West	61° 17′

The form $3\ 1\ 3$; $3\ \bar{P}^{1}\ 3$ Naumann; $1\ 3\ 1$ Miller; $D^{1}\ F^{\frac{1}{3}}\ H^{1}$ Brooke and Levy.

Axinite	North Polar distance	76° 34′	Longitude West	69° 8′

To determine the position of the poles of any form on the sphere of projection.—If h, k and l be Miller's symbols for any face, and λ the north polar distance of the pole of one of its faces on the sphere of projection, and μ the longitude of that pole, west from the point where the axis O T_1 cuts the sphere, the point where the axis O Z cuts the sphere, or the pole of the face $\infty\,\infty\,1$, being taken as the north pole of the sphere.

$$\tan\phi = \frac{n}{k}\cos\gamma\tan\delta \qquad q = k\cos(45+\phi)\cot\delta\operatorname{cosec}\gamma\sec 45\sec\phi$$

$$\tan\theta = \frac{n}{l}\cos\beta\tan\epsilon \qquad q' = l\cos(45+\theta)\cot\epsilon\operatorname{cosec}\beta\sec 45\sec\theta$$

$$\tan\psi = \frac{q}{q'}\cos A \qquad r = q'\cos(45+\psi)\operatorname{cosec} A\sec 45\sec\psi$$

$$\tan\mu = \frac{q}{h} \qquad \tan\lambda = \frac{n}{r}\sec\mu$$

When $h = o$ and $k = o$ then $q = o$; when $h = o$ and $l = o$ then $q' = o$; and when $q = o$ and $q' = o$, then $r = o$. θ, ϕ and ψ are subsidiary angles.

TWIN CRYSTALS.

A *Twin Crystal*, or *Macle Crystal*, is composed of two crystals, or similar portions of two crystals joined together in such a manner that one would come into the position

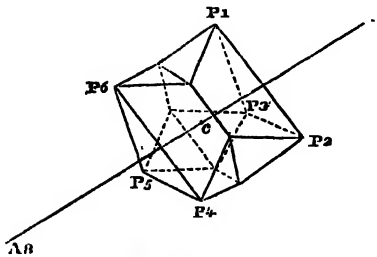


Fig. 359.

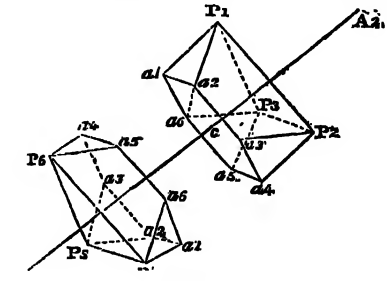


Fig. 360.

of the other by revolving through two right angles round an axis which is perpendicular to a plane, which either is, or may be, a face of either crystal. From this property, twin crystals are called *hemitrope crystals*, by Haüy.

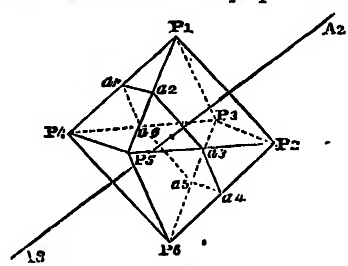


Fig. 361.

The axis about which the crystals are supposed to revolve is called the twin axis, and the plane to which it is perpendicular the twin plane.

Twin Crystal of the Octahedron about the Octahedral Axis.—If we bisect the edges $P_1 P_4$ (Fig. 361), $P_1 P_5$, $P_5 P_2$, $P_2 P_6$, $P_3 P_6$, and $P_3 P_4$ of the octahedron $P_1 P_5 P_6$, by the points a_1, a_2, a_3, a_4, a_5 and a_6, and join these points; then suppose the octahedron cut in half by a plane passing through $a_1\, a_2\, a_3\, a_4\, a_5\, a_6$, and a wire axis or pin passed through the centre of the octahedron perpendicular to the plane $a_1 a_2 a_3\, a_4 a_5 a_6$. This axis will correspond to the octahedral axis $A_2\, A_8$ (Fig. 17), if the octahedron be inscribed in a cube, as in Fig. 21.

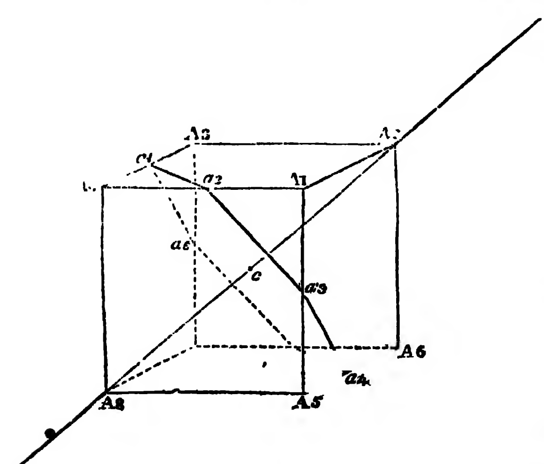


Fig. 362.

Let now the lower portion of the octahedron be separated from the upper and made to revolve through an angle of 180°, round the axis $A_2\, A_8$, till it comes suc-

cessively into the position shown in Figs. 360 and 359; and a *twin crystal* will be formed. The plane a_1 a_2 &c. a_6, is the twin plane, and the line A_2 A_8, which is perpendicular to it, the twin axis.

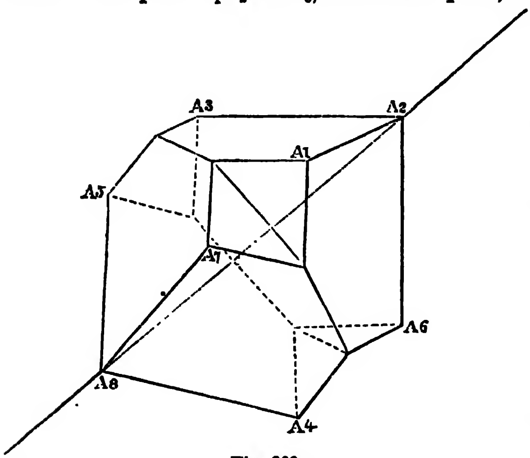


Fig. 363.

This twin crystal is of frequent occurrence among crystals of the diamond and the spinelle ruby.

Twin Crystal of the Cube about the Octahedral Axis.—By bisecting the edges of the cube A_4 A_3 (Fig. 362), A_1 A_4, A_1 A_5, A_5 A_6, A_6 A_7, A_7 A_3, in the points a_1 a_2 a_3 a_4 a_5 and a_6; making a section of it by a plane passing through these points, and causing the lower section to revolve through an angle of 180° round the axis A_2 A_8, when it will come into the position indicated in Fig. 363, we shall obtain a twin crystal of the cube.

The twin crystal of the octahedron (Fig. 361), and of the cube (Fig. 363), present cases of some of the faces being inclined to each other at re-entering angles. This is a general characteristic of twin crystals; though there are instances, of which the twin

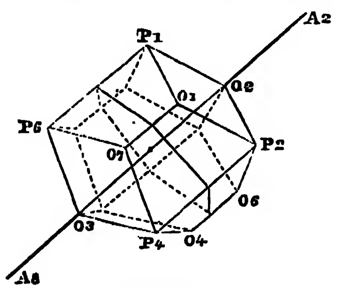


Fig. 364.

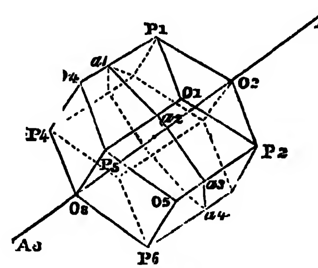


Fig. 365.

of the rhombic dodecahedron is one, where the twins are united without producing re-entering angles.

Twin Crystals of the Rhombic Dodecahedron about the Octahedral Axis.—Take points a_1 a_2 a_3 and a_4 on the edges of the rhombic dodecahedron (Fig. 365), such that O_4 a_1 is one-third of P_1 O_4; O_1 a_2 one-third of P_5 O_1; O_5 a_3 one-third of O_5 P_2, and O_6 a_4 one-third of O_6 P_6; join a_1 a_2 a_3 and draw a_1 a_6 parallel to a_3 a_4, a_6 a_5 to a_2 a_3, and a_5 a_4 to a_1 a_2. The plane passing through a_1 a_2 a_3 &c., a_6 will be perpendicular to the octahedral axis A_2 A_8; a section being made through this plane and the lower part of the rhombic dodecahedron made to revolve about the axis A_2 A_8 until it comes into the position (Fig. 364), a twin crystal will be formed, which has no re-entering angles.

It is not essential that the members of a twin crystal should be exactly the half of the form from which they are derived. Thus two sections of the octahedron, similar

to that shown in Fig. 11, may be united to form a twin. Sometimes the two members of the twin may both be completely formed, so as to produce the appearance of two crystals penetrating one another. Thus Fig. 366 represents each cube in Fig. 363

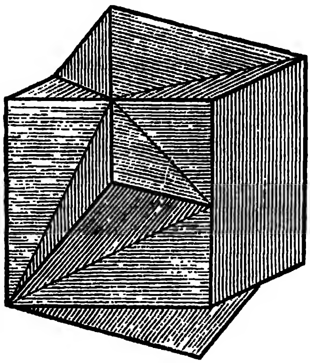


Fig. 366.

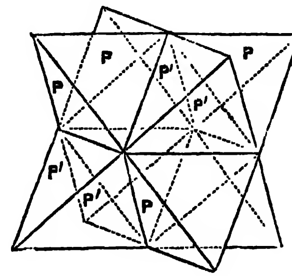


Fig. 367.

completed, and forming, as it were, two cubes penetrating each other. This form of twin crystal is frequently found in fluor spar and iron pyrites.

Fig. 367 represents two octahedrons of fahlerz, or gray copper ore, intersecting each other, and forming a twin crystal.

Nets for Twin Crystals of the Octahedron.

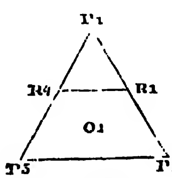


Fig. 368.

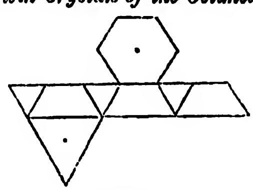


Fig. 369.

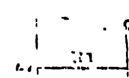


Fig. 370.

Prick off the points P_1 P_5 P_2 O_1 R_1 R_4 from Fig. 22; join P_1 P_5, P_5 P_2, P_1 P_2 and R_4 R_1, then one triangle similar and equal to P_1 P_5 P_2, three equal to P_1 R_4 R_1 and three trapeziums similar and equal to R_1 R_4 P_5 P_2, and a regular hexagon having its sides equal to R_1 R_4 arranged as in Fig. 369; will form the net for one member of the twin; the axis will pass through the point O_1 of the triangle P_1 P_5 P_2 and the centre of the hexagonal face.

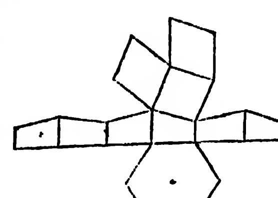


Fig. 371.

Net for the Twin Crystal of the Rhombic Dodecahedron.—Draw the rhomb P_1 O_1 O_2 P_2 (Fig. 370) similar and equal to the rhomb (Fig. 30). Through R_1 the centre of the rhomb draw the line a_1 R_1 a_2 perpendicular to P_1 O_2 or O_1 P_2. Then three rhombs similar and equal to P_1 O_2 P_2 O_1; six trapeziums similar and equal to P_1 O_1 a_2 a_1, and a regular hexagon having its sides equal to a_1 a_2, arranged as in Fig. 371, will form a net for one member of the twin. The twin axis will pass through the point where the three rhombs meet, and the centre of the hexagonal face.

When the crystallographic axes of the two members of the twin crystal are parallel to each other, as in the case of the twin, Fig. 367, so that the cleavages of the one are parallel to or continued one into the other without interruption; we cannot determine with certainty whether such crystals are to be considered as twins, or only single crystals whose faces are repeated with a certain degree of regularity. Thus it is doubtful whether Fig. 367 is a twin, or a regular combination of the positive and negative tetrahedrons, Figs. 92 and 93.

In pyrites the positive and negative pentagonal dodecahedrons, Figs. 113 and 114, and in the diamond the positive and negative six-faced tetrahedrons, Figs. 107 and 108, are united together in a similar manner, forming doubtful twins.

Twin Crystals, Cubical System.

Twin face parallel to a face of the octahedron.

Alabandine	Diamond	Galena	Pyrite
Blende	Fahlerz	Gold	Silver
Bornite	Fluor	Linneite	Spinelle
Copper	Gahnite	Magnetite	Tennantite

Twin face parallel to a face of the rhombic dodecahedron.

Diamond	Eulytine	Fahlerz	Pyrite

Twin Crystals Pyramidal System.

Twin face parallel to a face of the square prism $1 \infty \infty$.

Towanite

Twin face parallel to a face of the square prism $1\ 1 \infty$.

Scheelite

Twin face parallel to a face of the pyramid $1 \infty 1$.

Cassiterite	Fanjasite	Rutile	Scheelite	Towanite

Twin face parallel to a face of the pyramid $1 \infty 3$.

Rutile

Twin face parallel to a face of the pyramid $1\ 1\ 1$.

Hausmannite	Tin	Towanite

Twin face parallel to a face of the pyramid $1\ 1\ 3$.

Tin

Twin Crystals Rhombohedral System.

Twin face parallel to a face of the basal pinacoid $\infty \infty 1$.

Ankerite	Cinnabar	Hematite	Levine
Calcite	Dolomite	Ilmenite	Pyrargyrite
Chabasite	Gmelinite	Ice	Quartz

Twin face parallel to a face of the hexagonal prism of the second order $1\ 1 \infty$.

Phenakite

Twin face parallel to a face of the six-faced pyramid of the first order $1\ 2\ 1$.

Quartz

Twin face parallel to a face of the positive rhomboid $+ R$.

Calcite	Corundum	Hematite	Quartz	Pyrargyrite

Twin face parallel to a face of the positive rhomboid $+ \frac{1}{4} R$.

Tetradymite	Pyrargyrite

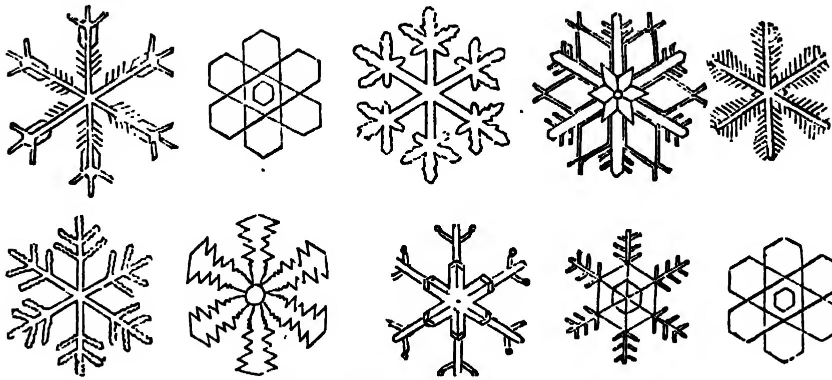
Twin face parallel to a face of the negative rhomboid $- \frac{1}{2} R$.

Ankerite	Bismuth	Chalybite
Arsenic	Calcite	Dioptase

Twin face parallel to a face of the negative rhomboid $- 2 R$.

Calcite

The following figures show some of the beautiful forms assumed by twin crystals of ice or snow.



Twin Crystals—Prismatic System.

Twin-face parallel to a face of the macro-pinacoid $\infty\ 1\ \infty$.
Wolfram.

Twin-face parallel to a face of the brachy-pinacoid $1\ \infty\ \infty$.
Struvite.

Twin-face parallel to a face of the prism of the 1st order $1\ 1\ \infty$.
Alstonite. Antimonsilber. Aragonite. Bournonite. Cerussite.
Epistilbite. Glaserite. Harmotome. Marcasite. Mispickel.
Phillipsite. Redruthite. Sternbergite. Stephanite. Strontianite.
Stromeyerite. Sulphur. Witherite. Zinckenite.

Twin-face parallel to a face of the prism of the 2nd order $1\ \infty\ 1$.
Chrysoberyl. Leadhillite. Manganite.

Twin-face parallel to a face of the prism of the 2nd order $1\ \infty\ \frac{3}{2}$.
Staurolite.

Twin-face parallel to a face of the prism of the 2nd order $1\ \infty\ 2$.
Niobite.

Twin-face parallel to a face of the prism of the 2nd order $1\ \infty\ \frac{2}{3}$.
Wolfram.

Twin-face parallel to a face of the prism of the 3rd order $\infty\ 1\ 1$.
Marcasite. Mispickel. Smithsonite. Stilbite.

Twin-face parallel to a face of the pyramid of the 1st class $1\ 1\ \frac{1}{2}$.
Redruthite. Stromeyerite.

Twin-face parallel to a face of the pyramid of the 2nd class $1\ \frac{3}{2}\ \frac{3}{2}$.
Staurolite.

Twin Crystals—Oblique System.

Twin-face parallel to a face of the basal pinacoid $\infty\ \infty\ 1$.
Epidote. Felspar. Mirabilite. Sphene.

Twin-face parallel to a face of the ortho-pinacoid $1\ \infty\ \infty$.
Acmite. Amphibole. Augite. Epidote.*
Felspar. Feuerblende. Freieslebenite.
Gypsum. Linarite. Malachite.
Rhyacolite. Scolezite. Vauquelinite.

Twin-face parallel to a face of the prism 3 1 ∞.
Felspar.

Twin-face parallel to a face of the prism 1 ∞ 1.
Chessylite. **Gypsum.** **Natron.** **Sphene.** **Whewellite.**

Twin-face parallel to a face of the prism 1 ∞ 2.
Humite.

Twin-face parallel to a face of the prism ∞ 1 1.
Woolastonite.

Twin-face parallel to a face of the prism ∞ 1 2.
Felspar. **Rhyacolite.**

Twin Crystals—Anorthic System.

Twin-face parallel to a face of the basal-pinacoid ∞ ∞ 1.
Labradorite.

Twin-face parallel to a face of the macro-pinacoid ∞ 1 ∞.
Albite. **Christianite.** **Labradorite.** **Oligoclase.**

Twin-axis perpendicular to the plane passing through the poles of the forms $\bar{1}$ 1 ∞, ∞ 1 ∞, and 1 1 ∞.
Albite.

Twin-axis perpendicular to a face of the plane passing through the poles of the forms ∞ ∞ 1, 1 ∞ 1, and 1 ∞ 2.
Albite. **Oligoclase.**

Twin-axis perpendicular to a face of the plane passing through the poles of the forms 1 ∞ ∞, 1 1 ∞, and $\bar{1}$ 1 ∞.
Sassoline.

Pseudomorphous Crystals.—Pseudomorphous crystals are those which present the form of a mineral differing from that of which they are composed. They may be produced by the decomposition of the crystal after it has been formed, or by another substance being deposited upon it so as to assume its form. Sometimes after another substance has been deposited on a crystal, the crystal may have been removed, and a third mineral deposited in its cast.

The following is a list of pseudomorphous substances quoted by Professor Miller from Blum :—

Pseudomorphous by Loss of an Ingredient.

Calcite	replacing crystals of	Gaylussite.
Quartz	,,	Heulandite and Stilbite.
Kyanite	,,	Andalusite.
Steatite	,,	Amphibole.
Copper	,,	Cuprite.
Argentite	,,	Pyrargyrite.

Pseudomorphous by the Addition of an Ingredient.

Gypsum	replacing crystals of	Karstenite.
Mica	,,	Pinite.
Valentinite	,,	Antimony.
Anglesite	,,	Galena.
Hematite	,,	Magnetite.
Limonite	,,	Hematite.
Malachite	,,	Cuprite.
Bornite and Towanite	,,	Redruthite.

Pseudomorphous by Exchange of Ingredients.

Baryte	replacing crystals of	Witherite and Barytocalcite.
Fluor and Gypsum	„	Calcite.
Calcite	„	Gypsum.
Magnesite	„	Calcite.
Calcedony	„	Datholite.
Jasper	„	Amphibole.
Opal and Cimolite	„	Augite.
Lithomarge	„	Topaz, Felspar, and Nepheline.
Kaolin	„	Felspar, Porzellanspath, and Leucite.
Mica	„	Andalusite, Felspar, Scapolite, and Tourmaline.
Mica, Hardfahlunite, Aspasiolite, Fahlunite, Esmarkite, Bonsdorffite, Chlorophyllite, Weissite, Plaseolite, Pyrargillite, Gigantollite, and Pinite	„	Cordierite.
Prehnite	„	Analcine, Mesotype, and Leonhardite.
Talc	„	Chiastolite, Kyanite, Couzeranite, Felspar, and Pyrope.
Stealite	„	Magnesite, Spinelle, Quartz, Andalusite, Chiastolite, Topaz, Felspar, Mica, Scapolite, Tourmaline, Staurolite, Garnet, Idocrase, and Augite.
Serpentine	„	Spinelle, Mica, Garnet, Augite, Chondrodite, Amphibole, and Olivine.
Amphibole	„	Augite.
Chlorite	„	Felspar, Garnet, and Amphibole.
Pyrolusite, Hausmannite, Manganite, Valentinite, Stibiolite, and Kermes	„	Antimonite.
Wismuthocker	„	Patrinite.
Minium	„	Galena and Cerussite.
Galena	„	Pyromorphite.
Pyromorphite	„	Galena and Cerussite.
Cerussite	„	Galena, Anglesite, Leadhillite.
Wulfenite	„	Galena.
Magnetite	„	Chalybite.
Hematite	„	Göthite, Pyrite, Pharmacosiderite, and Chalybite.
Limonite	„	Marcasite, Skorodite, and Chalybite.
Stilpnosiderite	„	Vivianite.
Pyrite	„	Mispickel.
Melanterite	„	Pyrite.
Grünerde	„	Augite.
Pseudotriplite	„	Triphyline.
Wolfram	„	Scheelite.
Erythrine	„	Smaltite.
Kupferschwärze	„	Redruthite.
Kupferpecherz	„	Towanite, and Fahlerz.
Coveline	„	Towanite.
Malachite	„	Chessylite, Towanite, and Fahlerz.
Chessylite	„	Fahlerz.

Pseudomorphous by total Change of Substance.

Graphite	replacing crystals of	Pyrite.
Salt	„	Magnesite.
Karstenite, Gypsum, and Polyhalite		Salt.
Quartz		Baryte, Fluor, Gypsum, Calcite, Barytocalcite, Magnesite, Scheelite, Galena, Cerussite, Hematite, Pyrite, and Chalybite.
Prasen and Eisenkiesel		Calcite.
Chalcedony		Baryte, Fluor, Calcite, Magnesite, and Pyromorphite.
Carnelian		Calcite.
Hornstone		Fluor, Calcite, Mica, and Chalybite.
Semiopal		Calcite.
Lithomarge		Fluor.
Pyrite		Quartz, Stephanite, and Pyrargyrite.

Marcasite	replacing crystals of	Pyrargyrite.
Chalybite	,,	Baryte, Calcite, and Magnesite.
Malachite	,,	Calcite and Cerussite.
Crysocolla	,	Cerussite.
Feldstine, Meerschaum, and Pyrolusite	,	Calcite.
Pyrolusite	,	Magnesite.
Hausmannite and Manganite	,	Calcite.
Psilomelane	,	Baryte, Fluor, and Pharmacosiderite.
Smithsonite	,	Fluor, Calcite, Magnesite, Galena, and Pyromorphite.
Kassiterite	,	Felspar.
Cerussite	,	Baryte and Fluor.
Stilpnosiderite	,	Magnesite and Calamine.
Hematite	,	Fluor and Calcite.
Limonite	,	Baryte, Fluor, Calcite, Magnesite, Quartz, Comptonite, Blende, Galena, Pyromorphite, Cerussite, and Cuprite.
Pyrite	,	Baryte and Calcite.
Marcasite	,	Fluor and Calcite.

Pseudomorphism of dimorphous substances.

Calcite	replacing crystals of	Aragonite.
Marcasite	,,	Pyrite.

Pseudomorphism after organic forms,

Calcite, Baryte, Celestine, Fluor, Gypsum, Quartz, Opal, Talc, Pyrite, Hematite, Limonite, Chalybite, Blende, Galena, Cerussite, Copper, Towanite, Bornite, Redruthite, and Cinnabar.

Dimorphism.—Bodies of the same chemical composition, which crystallize in forms belonging to two different systems, or if in the same system in forms which can only be referred to two different sets of parameters, which will be indicated by their having different angular elements, are said to be *dimorphous*. Sulphur and carbonate of lime are instances of dimorphous substances, the system of crystallization to which each of these will belong seems to depend upon the temperature at which the crystal is formed. Titanic acid is tri-morphous, as Brookite it is prismatic, as Anatase and Rutile it is pyramidal, but the angular elements of Anatase and Rutile differ.

Isomorphism—Substances forming crystals belonging to the same system, if their angular elements differ but a few minutes, are said to be *isomorphous*, *homœmorphous*, or *plesiomorphous*. Alumina, red oxide of iron, and oxide of chrome; carbonates of lime (calcite), of magnesia (magnesite), of protoxide of iron (chalybite), of protoxide of manganese (diallogite), of oxide of zinc: antimony, bismuth, arsenic, and tellurium form three isomorphous groups of the rhombohedral system. Carbonate of lime (aragonite), of barytes, of strontian, and of oxide of lead; Sulphate of potash, seleniate of potash, chromate of potash, and manganate of potash; sulphate of soda, seleniate of soda, sulphate of oxide of silver, and seleniate of oxide of silver, are three isomorphous groups of the prismatic system. Gypsum, sulphate of iron, and seleniate of iron is an isomorphous group of the oblique system. Seleniate of oxide of copper, sulphate of oxide of copper, and sulphate of protoxide of manganese are isomorphous forms of the anorthic system.

Any chemical elements or compound substances which will replace each other without altering the crystallographic character of the compound in which the change takes place, are also said to be *isomorphous*. Thus in the garnets and alums, iron, calcium, magnesium, and aluminium replace each other, and are therefore said to be isomorphous.

Goniometers.—Instruments which enable us to determine the angles at which adjacent faces of crystals are inclined to each other, are called *goniometers*. Professor Miller's description of the method of using them having been given in the chemical department of this work, we here quote Mr. Brooke's, from the "Encyclopædia Metropolitana:"—

"The mutual inclination of any two planes, as of *a* and *b*, Fig. 372, is indicated by the angle formed by two lines, *e d*, *e f*, drawn upon them from any point *e* on the edge at which they meet, and perpendicular to that edge.

"Now it is known that if two right lines, as *g f*, *d h*, Fig. 373 cross each other at any point *e*, the opposite angles *d e f*, *g e h*, are equal. If, therefore, the lines, *g f*, *d h*, are supposed to be very thin and narrow plates, and to be attached together

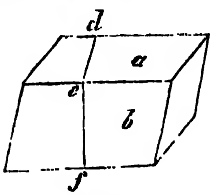


Fig. 372.

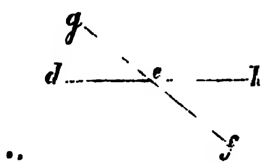


Fig. 373.

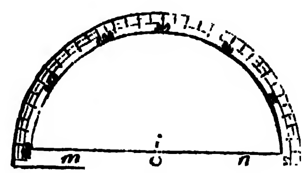


Fig. 374.

by a pin at *e*, serving as an axis to permit the point, *f*, to be brought nearer either to *d*, or to *h*, and that the edges, *e d*, *e f*, of those plates, are applied to the planes of the crystal, Fig. 372, so as to rest upon the lines, *e d*, *e f*, it is obvious that the angle, *g e h*, of the moveable plates would be exactly equal to the angle, *d e f*, of the crystal.

"The common goniometer is a small instrument for measuring this angle, *g e h*, of the moveable plates. It consists of a semicircle, Fig. 374, divided into 360 equal parts, or half degrees, and a pair of moveable arms, *d h*, *g f*, Fig. 375, the semicircle having a pin at *i*, which fits into a hole in the moveable arms at *e*.

"The method of using this instrument is to apply the edges, *d e*, *e f*, of the moveable arms to the two adjacent planes of any crystals, so that they shall actually touch or rest upon those planes *in directions perpendicular to their edge*. The arm, *d h*, is

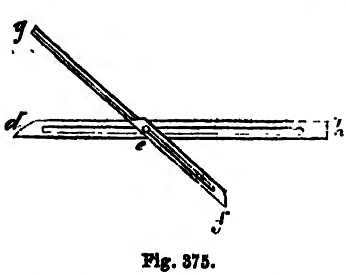


Fig. 375.

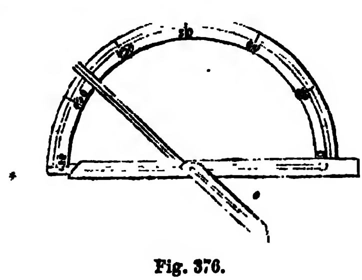


Fig. 376.

then to be laid on the plate, *m n*, of the semicircle, Fig. 374, the hole at *e* being suffered to drop on the pin at *i*, and the edge nearest to *h* of the arm *g e* will then indicate on the semicircle, as in Fig. 376, the number of degrees which the measured angle contains.

"When this instrument is applied to the planes of a crystal, the points, *d* and *f*, Fig. 375, should be previously brought sufficiently near together for the edges, *d e*, *e f*, to form a more acute angle than that about to be measured. The edges being then gently pressed upon the crystal, the points, *d* and *f*, will be gradually separated, until the edges coincide so accurately with the planes that no light can be perceived between them.

"The common goniometer is, however, incapable of affording very precise results, owing to the occasional imperfection of the planes of crystals, their frequent minuteness, and the difficulty of applying the instrument with the requisite degree of precision.

"The more perfect instrument, and one of the highest value to crystallography, is the reflecting goniometer, invented by Dr. Wollaston, which will give the inclination of planes whose area is less than $\frac{1}{100000}$ of an inch, to less than a minute of a degree. This instrument has been less resorted to than might, from its importance to the science, have been expected, owing, perhaps, to an opinion of its use being attended with some difficulty. But the observance of simple rules will render its application easy. The principle of the instrument may be thus explained:—

"Let *a b*, Fig. 377 represent a crystal, of which one plane only is visible in the

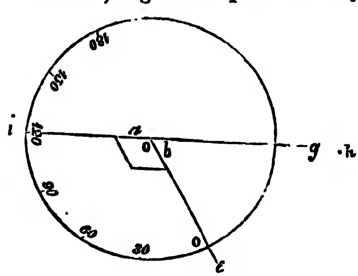


Fig. 377.

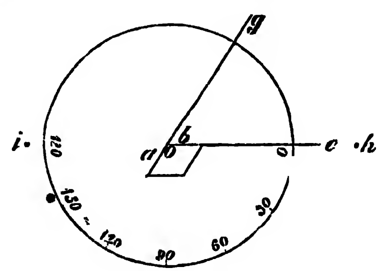


Fig. 378.

figure, attached to a circle, graduated on its edge, and moveable on its axis at *o*; and let *a* and *b* mark the position of the two planes whose mutual inclination is required.

"And let the lines, *o e*, *o g*, represent imaginary lines, resting on those planes in directions perpendicular to their common edge, and the dots at *i* and *h*, some permanent marks in a line with the centre, *o*.

"Let the circle be in such a position that the line, *o e*, would pass through the dot at *h*, if extended in that direction, as in Fig. 378.

"If the circle now be turned round with its attached crystal, as in Fig. 377, until the imaginary line, *o g*, is brought into the position of the line, *o e*, in Fig. 378, the number 120 will stand opposite the dot at *i*. This is the number of degrees at which the planes *a* and *b* incline to each other. For if the line *o g* be extended in the direction *o i*, as in Fig. 377, it is obvious that the lines, *o e*, *o i*, which are perpendicular to the common edge of the planes, *a* and *b*, would intercept exactly 120° of the circle.

"Hence an instrument constructed upon the principle of these diagrams is capable of giving with accuracy the mutual inclination of any two planes which reflect objects with sufficient distinctness, if the means can be found for placing them successively in the relative positions shown in the two preceding figures.

"This purpose is effected by causing an object, as the line at *m* (Fig. 379), to be reflected successively from the two planes, *a* and *b*, at the same angle. It is well known that the images of objects are reflected from bright planes at the same angle as that at which their rays fall on those planes; and that when the image of an object reflected from a horizontal plane is observed, it appears so much below the reflecting surface as the object itself is above.

"If, therefore, the planes *a* and *b* (Fig. 379) are successively brought into such positions as will cause the reflection of the line at *m*, from each plane, to

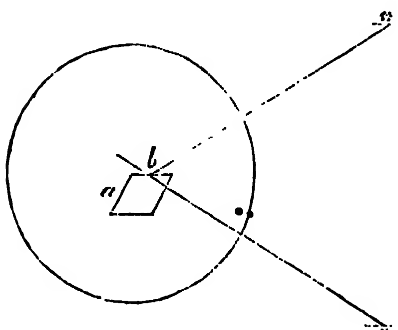


Fig. 379.

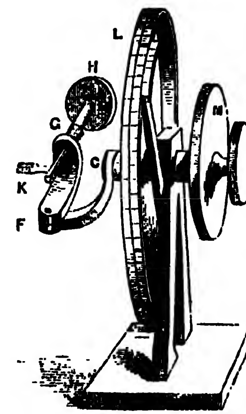


Fig. 380.

appear to coincide with another line at *n*, both planes will be successively placed in the relative positions of the corresponding planes in Figs. 377 and 378. To bring the planes of any crystal successively into these relative positions, the following directions will be found useful.

"The instrument, as shown in the sketch (Fig. 380) should be first placed on a pyramidal stand, and the stand on a small steady table, about six to ten or twelve feet from a flat window. The graduated circular plate should stand perpendicularly from the window, the pin GH being horizontal, not in the direction of the axis, as it is usually figured, but with the slit end nearest to the eye.

"Place the crystal which is to be measured on the table, resting on one of the two planes whose inclination is required, and with the edge, at which those planes meet, nearest and parallel to the window.

"Attach a portion of wax, about the size of *d*, to one side of a small brass plate, *c* (Fig. 381); lay the plate on the table with the edge, *f*, parallel to the window, the side to which the wax is attached being uppermost, and press the end of the wax against the crystal until it adheres; then lift the plate with its attached crystal, and place it in the slit of the pin GH, with that side uppermost which rested on the table.

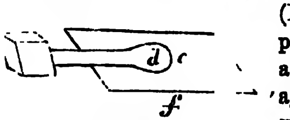


Fig. 381.

"Bring the eye now so near the crystal, as, without perceiving the crystal itself, to permit the images of objects reflected from its planes to be distinctly observed, and raise or lower that end of the pin GH which has the small circular plate on it, until one of

the horizontal upper bars of the window is seen reflected from the upper or first plane of the crystal, corresponding with the plane *a* (Fig. 377), and until the image of the bar appears to touch some line below the window, as the edge of the skirting-board where it joins the floor.

"Turn the pin GH on its own axis also, if necessary, until the reflected image of the bar of the window coincides accurately with the observed line below the window.

"Turn now the small circular handle, S, on its axis, until the same bar of the window appears reflected from the second plane of the crystal corresponding with plane *b* (Figs. 377 and 378), and until it appears to touch the line below; and having, in adjusting the *first* plane, turned the pin GH *on its axis*, to bring the reflected image of the bar of the window to coincide accurately with the line below, *now move the lower end of the pin laterally*, either towards or from the instrument, in order to make the image of the same bar, reflected from the second plane, coincide with the same line below.

"Having ascertained by repeatedly looking at, and adjusting both planes, that the image of the horizontal bar, reflected successively from each plane, coincides with the observed lower line, the crystal may be considered ready for measurement.

"Let the 180° on the graduated circle be now brought opposite the 0 of the vernier at L, by turning the handle, M; and while the circle is retained accurately in this position, bring the reflected image of the bar from the *first* plane to coincide with the line below, by turning the *small* circular handle, S. Now turn the graduated circle, by means of the handle, M, until the image of the bar, reflected from the *second* plane, is also observed to coincide with the same line below. In this state of the instrument the vernier at L will indicate the degrees and minutes at which the two planes are inclined to each other.

"The accuracy of the measurements taken with this instrument will depend upon the precision with which the image of the bar, reflected successively from both planes, is made to appear to coincide with the same line below; and also upon the 0, or the 180°, on the graduated circle, being made to stand precisely even with the lower line of the vernier, when the first plane of the crystal is adjusted for measurement. A wire being placed horizontally between two upper bars of the window, and a black line of the same thickness being drawn parallel to it below the window, will contribute to the exactness of the measurement, by being used instead of the bar of the window and any other line.

"Persons beginning to use this instrument are recommended to apply it first to the measurement of fragments at least as large as that represented in Fig. 381, and of some substance whose planes are bright. Crystals of carbonate of lime will supply good fragments for this purpose, if they are merely broken by a slight blow of a small hammer.

"For accurate measurement, however, the fragments ought not, when the planes are bright, to exceed the size of that shown in Fig. 380, and they ought to be so placed on the instrument, that a line passing through its axis should also pass through the centre of the small minute fragment which is to be measured. This position on the instrument ought also to be attended to when the fragments of crystal are large. In which case the common edge of the two planes, whose inclination is required, should be brought very nearly to coincide with the axis of the goniometer; and it is frequently useful to blacken the whole of the planes to be measured, except a narrow stripe on each close to the edge over which the measurement is to be taken."

MINERALOGY.

The science which enables us to classify and arrange those inorganic productions of nature which are called minerals, and enables us to identify or distinguish them from one another, is termed *mineralogy.*

Mineral.—By the word mineral we understand all substances found in nature, which are homogeneous or of the same composition throughout their structure, and do not owe their origin to the action of animal or vegetable life. This definition excludes all rocks which are variable in their character and composition, as well as all substances, such as coal, which are products of vegetable life. Some of these are retained in most descriptions of minerals though they do not strictly belong to the subject of mineralogy.

Species of Minerals.—The various members of the mineral kingdom which essentially differ from one another are divided into *kinds* or *species.* By far the majority of mineral substances are found to assume definite mathematical forms, bounded, for the most part, by plane surfaces and straight lines—these are called *crystals.* The subject of crystallography we have already discussed at some length, particularly in its relation to minerals. Generally speaking, substances which differ in chemical composition from other substances constitute distinct mineral species; again, substances which agree in chemical constitution, but differ in the character of their crystalline forms, are divided into separate mineralogical species. Thus native gold, silver, and copper, which have the same crystalline forms, but differ in chemical composition, give three distinct species of minerals. Calcite and aragonite,—which have the same chemical composition, being both carbonate of lime, but present different kinds of crystalline forms, one series belonging to the rhomboidal and the other to the prismatic system,—constitute two distinct species. Difference in chemical composition, independently of crystalline form, or difference in the class of crystalline form, while the chemical composition remains the same, principally determine the division of minerals into species. This rule does not hold true universally, for some bodies admit of considerable change in their chemical composition without affecting their form and many other properties—several classes of such substances, of which the *garnets* and *alums* may be taken as an illustration, have by the common consent of mineralogists been considered as similar species, though differing from one another in chemical composition.

Characteristics of Minerals.—The crystalline form and chemical constitution of minerals are the principal characteristics by which, when known, their species and names may be discovered. Though these, in general, are sufficient for the identification of a mineral; yet, when the crystalline form is not apparent, or the chemical constitution determined without great trouble, there are many other characteristics which will enable us to describe and identify the species. The chief of these are the hardness, specific gravity, fracture, lustre, colour, brittleness, flexibility, malleability, taste, smell, and other natural properties of the substance. Sometimes the optical and electrical properties afford assistance.

Crystalline Form.—This subject has already been discussed at such considerable length, that it is unnecessary to say anything more here than to quote from Dana that, " To learn to distinguish minerals by their colour, weight, and lustre, is so far very well; but the accomplishment is of a low degree of merit, and when most perfect makes but a poor mineralogist. But when the science is viewed in the light of chemistry and crystallography, it becomes a branch of knowledge perfect in itself, and surprisingly beautiful in its exhibitions of truth. We are no longer dealing with pebbles of pretty shapes and tints, but with objects modelled by a divine hand, and every additional fact becomes to the mind a new revelation of His wisdom."

Chemical Composition.—There are sixty-two or sixty-three elementary bodies known (See CHEMISTRY, page 29); all species of minerals are formed by some one of these elements, or else result from their combinations. The following is a list of their symbols and chemical equivalents :—

Ag, Argentum (silver)	1349·01	Na, Natrium (sodium)	287·17
Al, Aluminium	170·42	Ni, Nickel	369·14
As, Arsenic	936·48	Nb, Niobium	
Au, Aurum (gold)	2456·72	N, Nitrogen	175·25
Ba, Barium	854·85	Nr, Norium	
Bi, Bismuth	2660·75	Os, Osmium	1242·60
B, Boran	136·31	O, Oxygen	100·00
Br, Bromine	999·63	Pb, Plumbum (lead)	1294·50
Cd, Cadmium	696·77	Pd, Palladium	662·54
Ca, Calcium	250·00	Pl, Pelopium	
C, Carbon	75·00	P, Phosphorus	391·55
Ce, Cerium	590·80	Pt, Platinum	1233 50
Cl, Chlorine	443·20	R, Rhodium	652·00
Cr, Chrome	349·83	Rt, Ruthenium	
Co, Cobalt	368·44	Se, Selenium	495·30
Cu, Cuprum (copper)	396·00	Si, Silicon	184·88
D, Didymium	620·00	Sr, Strontium	545·60
Do, Donorium		S, Sulphur	200·00
E, Erbium		Sb. Stibium (antimony)	1612·90
Fe, Ferrum (iron)	350·06	Sn, Stannium (tin)	735·30
F, Fluorine	235·71	Ta, Tantalum	1148·40
G, Glucinium	58·08	Te, Tellurium	801·80
H, Hydrogen	12·50	Tr, Terbium	
Hg, Hydrargyrum (mercury)	1250·80	Th, Thorium	743·90
I, Iodine	1385·57	Ti, Titanium	301·60
Ir, Iridium	1232·00	U, Uranium	742·90
K, Kalium (potassium)	488·94	Va, Vanadium	856·90
La, Lanthanium	588·00	W, Wolfram (scheelium)	1188·40
L, Lithium	81·85	Y, Yttrium	402·50
Mg, Magnesium	157·75	Zn. Zinc	406·60
Mn, Manganese	344·44	Zr, Zirconium	281·20
Mo, Molybdenum	596·10		

The letters or symbols placed before these elementary bodies enable us to express with great conciseness the chemical composition of any mineral, and the numbers which follow them, to determine the comparative weights of its component elements.

Thus, ZnO represents the red oxide of zinc, spartalite, consisting of one equivalent of zinc and one of oxygen.

FeS^2, iron pyrites consisting of one equivalent of iron and two equivalents of sulphur.

Fe^2O^3 the red oxide of iron or hematite, consisting of two equivalents of iron and three of oxygen.

AsO^5, arsenic acid, consisting of one equivalent of arsenic and five equivalents of oxygen.

HO, water consisting of one equivalent of hydrogen and one of water.

Pharmacosiderite, an arseniate of iron, is represented by the more complex symbol $3Fe^2O^3 + 2AsO^5 + 12HO$, showing that it consists of 3 equivalents of red oxide of iron, 2 of arsenic acid, and 12 of water. The following formulæ will show the relative weights of the constituents of the above substances.

Spartalite.				Iron Pyrites.			
Zn = 1 equiv. of	Zinc	= 406·60 or	80·26	Fe = 1 equiv. of	Iron	= 350·00 or	46·67
O = 1 „	Oxygen	= 100.00	19·74	S^2 = 2	Sulphur	= 400·00	53·30
ZnO = 1 „	Spartalite	= 506·60	100·00	FeS^2 = 1	Iron Pyrites	= 750·00	100·00

The first column is obtained by multiplying the equivalent number of the elements by the number of its equivalents in the substance, and shows that 506·60 parts by weight of spartalite contain 406·60 parts of zinc and 100 parts of oxygen, or that 750 parts of iron pyrites contain 350 parts of iron and 400 of sulphur.

The second column shows that 100 parts by weight of spartalite contain 80·26 parts of zinc and 19·74 of oxygen; and 100 parts of iron pyrites contain 46·67 of iron and 53·30 of sulphur. This column is found by multiplying the number for the zinc, oxygen, iron, or sulphur of the first column by 100 and dividing it by the equivalent number for the substance, thus,

$$\frac{406{\cdot}60 \times 100}{506{\cdot}60} = 80{\cdot}26 \quad \frac{100{\cdot}00 \times 100}{506{\cdot}60} = 19{\cdot}74 \quad \frac{350 \times 100}{750} = 46{\cdot}67 \quad \frac{400 \times 100}{750} = 53{\cdot}30$$

To determine the relative weights of the constituents of pharmacosiderite we have the following calculations:—

Fe^2 = 700·00	As = 936·48	H = 12·50
O^3 = 300·00	O^5 = 500·00	O = 100·00
Fe^2O^3 = 1000·00	AsO^5 = 1436·48	HO = 112·50
3	2	12
$3Fe^2O^3$ = 3000·00	$2AsO^5$ = 3972·96	12HO = 1350·00

$3Fe^2O^3$ = 3 equivalents of	the Red oxide of Iron	= 3000·00 or	41·53
$2AsO^5$ = 2 „ „	Arsenic acid	= 3972·96	39·78
12HO = 12 „ „	Water	= 1350·00	18·69
1 „ „	Pharmacosiderite	= 8322·96	100·00

There are two methods of investigating the chemical composition of a mineral—the qualitative and the quantitative. The qualitative analysis determines the nature of the constituents, and the quantitative their relative proportions. For the method of conducting these analyses we must refer the student to the science of chemistry, contenting ourselves with expressing the chemical composition of the mineral in symbols, according to the best authorities, and indicating after the letter B whether they are fusible or not before the blowpipe, and also whether they are soluble or insoluble in acids.

Hardness.—The comparative hardness of minerals is of great assistance in determining their species, and it is a matter of great regret that this important pro-

perty has not been more accurately observed. The following scale introduced by Mohs is that generally adopted for indicating the hardness of minerals :—

1. TALC.	3. CALCITE.	5. APATITE.	7. QUARTZ.	9. CORUNDUM.
2. ROCK SALT.	4. FLUOR.	6. FELSPAR.	8. TOPAZ.	10. DIAMOND.

The specimens of the above minerals used for testing the hardness of other minerals are generally fragments of transparent or cleavable varieties.

The hardness of talc is said to be 1, of rock salt 2, of calcite 3, and so on. A mineral which neither scratches nor is scratched by any member of the series is said to be of the same hardness. Thus, a mineral which neither scratches nor is scratched by quartz is said to be of the hardness of 7, generally indicated thus, H 7. A mineral which scratches calcite, and is scratched by fluor, is said to be of a degree of hardness between 3 and 4, which is indicated by 3·25, 3·5, or 3·75, according as it is regarded as $\frac{1}{4}$, $\frac{1}{2}$, or $\frac{3}{4}$ harder than calcite, No. 3. To ascertain these fractional degrees of hardness the three minerals are passed successively over a finely-cut hard steel file, one end of the file being held by the hand, while the other rests on a table. The degree of hardness of the intermediate substance is determined by observing the degree of resistance it affords to the file, the quantity of powder left on its surface, and the sound produced by the operation. Care must be taken to use specimens nearly of the same form and size, and also of great purity.

Streak.—This is a property examined by scratching the mineral by a substance harder than itself, or when it is not too hard, by rubbing it on a piece of unglazed porcelain. A writing diamond will scratch all other minerals; but a fragment of corundum, quartz, or a hard steel point, will be sufficient for most. The scratch may be a rough or smooth line, and it may be accompanied by the powder of the mineral.

The colour of this powder determines the colour of the streak, and it is distinguished as shining or dull, according as the scratch is of a greater or less lustre than the surface of the mineral scratched.

Specific Gravity.—Equal volumes of different substances are frequently found to differ in their weights. To determine the relative weights, or the specific gravity, of equal volumes of substances, distilled water at a temperature of 60° of Fahrenheit, or 15·55° centrigrade, is taken as the standard unit of comparison. As it would be extremely difficult to obtain equal volumes of the substances whose specific gravity is required, advantage is taken of the hydrostatical property, that a body immersed in water displaces a mass of water equal in volume to itself, and has its weight diminished by that of the equal volume of water it displaces. The *specific gravity* of a body being the ratio of its weight to an equal volume of distilled water at the temperature of 60° Fah., all we have to do to determine it, is to weigh the substances first in air, and then in distilled water at 60° Fah. For this purpose the *hydrostatic balance* (Fig. 382) is made use of.

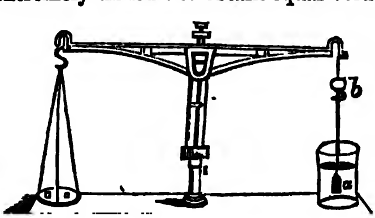


Fig. 382.

The hydrostatic balance is an ordinary balance, the scale pan of which is removed from one side, and replaced by a counterpoise *b*, which balances the other scale pan; under *b* is placed a hook, to which the substance to be weighed is suspended by a fine

fibre or platinum wire. For accurate experiments the balance should be sufficiently delicate to weigh to the one-hundredth part of a grain. Let A be the weight of the substance in air, W its apparent weight when suspended in water, and S G its specific gravity—then:

$$S\,G = \frac{A}{A - W}$$

When great accuracy is required, it may be necessary to take into account the weight of the mass of air displaced by the body when weighed in air. Since water is 815 times heavier than air, we must subtract from the specific gravity obtained above—

$$\frac{W}{815\,(A - W)}$$

Thus in a specimen of cordierite, whose weight in air is 311·91 grains, weight in water 195·46 grains.

$$\text{Here } S\,G = \frac{311{\cdot}91}{311{\cdot}91 - 195{\cdot}46} = 2{\cdot}678$$

If we take into account the weight of the air displaced when it is weighed in air, we must deduct from the above—

$$\frac{195{\cdot}46}{815 \times (311{\cdot}91 - 195{\cdot}46)} = {\cdot}002$$

which makes the corrected specific gravity 2·676. The bubbles of air which attach themselves to the surface of the mineral when suspended in water, are removed by boiling the water in which it is suspended briskly for some minutes, the whole being left to cool down to the temperature of 60° Fah.

If the mineral be so light as to float on the water, a sinker of brass, or some other substance whose apparent weight when suspended by itself in the distilled water is B, is attached to it, so as to cause it to sink.

Let A be the weight of the light mineral, B that of the sinker suspended by itself in the distilled water, C the weight of A and B when suspended in the water together; then in this case

$$S\,G = \frac{A}{A + B - C}$$

Thus, to find the specific gravity of a substance which weighs 20 grains in air, it is sunk by a weight which weighs 87·22 grains when immersed by itself in water; the two substances being suspended in the water together, weigh 23·89 grains. In this case

$$S\,G = \frac{20}{20 + 87{\cdot}22 - 23{\cdot}89} = \frac{20}{83{\cdot}33} = {\cdot}240$$

If the mineral can only be obtained in small fragments, or if it be supposed to contain vacuities it must be reduced to fine powder, and the specific gravity bottle (Fig. 383) made use of. This instrument is equally applicable for the determination of the specific gravity of solids or fluids. It consists of a thin glass bottle of a globular shape, and is generally made to contain either 500 or 1,000 grains of distilled water at 60° Fah. It is furnished with a ground glass stopper which is pierced through the centre with a straight hole of very fine bore. The object of this is, that when

the bottle is filled up to the neck with water or any other liquid, the stopper may be inserted, and, the excess of liquid escaping through the hole in the stopper, the bottle may be filled with a definite volume of liquid. Suppose our object is to find the specific gravity of a liquid, and that we use a 1,000 grain bottle, we proceed as follows:—Having placed the empty bottle in one pan of a balance, we counterpoise it by a weight in the other; we then fill the bottle with the liquid at 60° Fah. in the way described, wipe it dry, replace it in the scales and restore the equilibrium by adding more weights. The weight added is evidently that of the liquid, but as the same volume of water at 60° weighs 1,000 grs., if the bottle be accurately made, the specific gravity of the liquid is equal to its weight expressed in grains divided by 1,000. As the bottles are seldom made with such accuracy as to contain exactly the right quantity of water, let W be the weight of bottle full of air, W′ its weight filled with distilled water at 60° Fah., then making an allowance for the weight of the air contained in the bottle, the weight of the water contained in the bottle will be

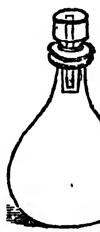


Fig. 383.

$$\frac{815(W - W')}{814}$$

and the weight of the bottle will be the difference between this quantity and W′. A piece of lead equal to this must be cut and kept as a counterpoise for the bottle. If a bottle, which has thus been found to contain 500·72 grains of water, be counterpoised by a piece of lead, and filled with sea water weighs 516·86 grains, the specific gravity of the sea water will be $\frac{516 \cdot 86}{500 \cdot 72}$ or 1·032.

To determine the specific gravity of a powdered mineral, a known weight M of the substance is introduced into the specific gravity bottle, which is then carefully filled with water and weighed.

Let M be the weight of the mineral introduced.

M′ the weight of the water it displaces in the bottle.

w the weight of the water which the bottle would contain when full.

W the weight of the bottle filled with the mineral and water, the lead counterpoise for the weight of the bottle itself being in the opposite scale.

Then the specific gravity of the substance $= \frac{M}{M'}$

$$\text{and } W = w + M - M', \text{ or, } M' = w + M - W$$

$$\text{and therefore } SG = \frac{M}{w + M - W}.$$

Let 86·02 grains of a mineral be introduced into a bottle formed to contain 500·72 grains of water, and the bottle filled with distilled water, let it then weigh 554·74 grains.

$$\text{Then } SG = \frac{86 \cdot 02}{500 \cdot 72 + 86 \cdot 02 - 554 \cdot 74} = 2 \cdot 688.$$

Nicholson's Areometer.—A cheap and convenient substitute for the balance is found in a little instrument represented in Fig. 384, and called *Nicholson's Areometer*, which we will briefly describe. V is a metallic ball or float having a descending hook, to which is hung a little weighted pan *l* to hold the substance which is weighed in water; the wire stem *f* supports a cup *c*. A mark *t*, on the stem, shows the point at

which the whole apparatus will float in a tall vessel of water, when a certain known weight (called the balance-weight) is put in the cup *e*. The specimen under examination must not exceed in weight the balance-weight, this being the limit of the instrument. Suppose the limit to be 100 grains. To find by this instrument the specific gravity of a substance, place it on *e*, and add weights till the instrument sinks to the mark *t*, the added weight being subtracted from 100, gives the weight of the specimen in air. Now place the specimen in the pan *l*, and again add weights to *e*. As much more weight on *e* will now be required as corresponds to the weight of a bulk of water equal to the specimen, which, it must be remembered, is buoyed up by a power just equal to such weight. The difference of weight thus found will be the divisor of the weight of the specimen, and the quotient will be the specific gravity sought.

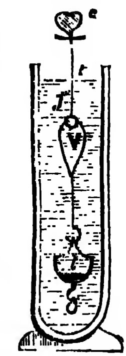


Fig. 384.

This instrument is generally made of brass or tin-plate, but may be more elegantly made of glass.

For example, put the specimen in balance-weight = ...	100·00	
Weights added to sink instrument to *t* = ...	22·57	grs.
Weight of specimen in air = ...	77·43	
Specimen placed in lower pan requires additional weights =	35·43	

$35{\cdot}43 - 22{\cdot}57 = 12{\cdot}86$, the weight of a like bulk of water; then $\frac{77{\cdot}43}{21{\cdot}86} = 6{\cdot}02$, the specific gravity sought.

When the specific gravity of two substances are known, by taking the specific gravity of their compound, we may find the relative weights of the two components. Thus, knowing the weight of a nugget of quartz and gold, by means of its specific gravity we can determine the weight of the gold contained in it.

Let G be the weight of gold in a nugget.	g its specific gravity.
Q the weight of the quartz in a nugget.	q its specific gravity.
N the weight of the nugget.	n its specific gravity.

then
$$G + Q = N$$
and
$$\frac{G}{g} + \frac{Q}{q} = \frac{N}{n}$$
From which equations we may obtain the following,
$$G = N.\ \frac{(n - q)\,g}{(g - q)\,n}$$

Thus, if the specific gravity of a nugget whose weight is 11½ oz. be 7·43, considering the specific gravity of the quartz as 2·62 and that of fine gold as 19·35, we shall have from the above formula

$$G = 11{\cdot}5\ \frac{7{\cdot}43 - 2{\cdot}62}{19{\cdot}35 - 2{\cdot}62} \times \frac{19{\cdot}35}{7{\cdot}43} = \frac{10703452{\cdot}5}{1243039} = 8{\cdot}6107.$$

or the amount of fine gold in the nugget will be about 8·6107 ounces.

The asperities on the surface of the quartz, as well as the cavities it contains, causes the nugget to displace more water than it should; consequently the amount of gold is rather understated. (Galbraith and Haughton's "Manual of Hydrostatics.")

Double Refraction and Polarized Light.—If a ray of light fall obliquely on a plate of glass or any other transparent medium, its direction is changed as it passes into the substance, and it is bent or refracted according to a law, known as the

law of sines. There are certain transparent substances which possess the power of splitting the refracted ray into two, one of which mostly follows the ordinary law of refraction, which belongs to transparent substances, and the other a more complicated law. Such substances are said to possess the power of double refraction. Calcite possesses this property in so high a degree, that all objects seen through it appear double. This is most strikingly observed in the very transparent varieties called Iceland spar.

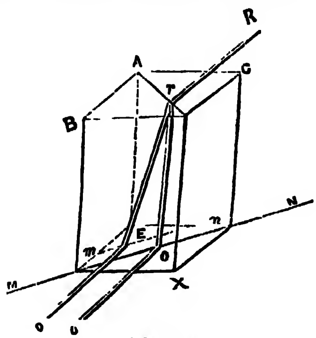


Fig. 385.

If a ray of light R r fall obliquely on any one of the surfaces of a cleavage rhomboid of calcite (Fig. 385), it will be divided on entering into the crystal into two rays, one r O in the same plane as the ray R r, following the ordinary law of refraction, and therefore called the ordinary ray; and the other, r E, following a more complicated law, and called the extraordinary ray. If the rhomboid be placed on a piece of paper having a black dot, the dot seen through the crystal will appear double, and one image of the dot will seem to be above the other; and in whatever position the rhomboid is placed, an imaginary line joining the two dots will always be parallel to the axis, P_1 P_2, which joins the two three-faced solid angles, P_1 and P_2, of the rhomboid (Fig. 386), formed by three equal and similar oblique angles. A line or printed characters viewed through the rhomboid will appear double; the distance between the two images will depend on the thickness of the rhomboid, being greater as the rhomboid is thicker.

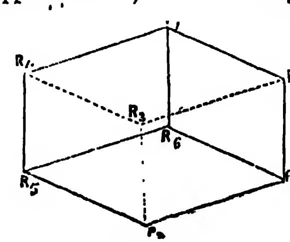


Fig. 386.

If the solid angles, P_1 and P_2, of the rhomboid be ground down and replaced by two triangular surfaces, as in Fig. 387, perpendicular to the axis, P_1 P_2, and these surfaces be polished, it will be found that a ray passing directly through these triangular surfaces will not suffer double refraction; and any object viewed through these planes will appear single. The axis, P_1 P_2, parallel to which there is no double refraction, is called the *optic axis* of the crystal. All transparent crystals, with the exception of those belonging to the cubical system, possess the property of double refraction, though few so powerfully as to cause objects seen through them to appear double. Nitrate of soda possesses the same crystalline form, cleavage, and the property of double refraction in the same degree of energy as calcite, and may be substituted for it in experiments on these optical peculiarities.

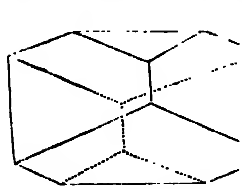


Fig. 387.

The light which passes through a doubly-refracting crystal suffers a peculiar change, which is called *polarization*. A ray of light which has been once split by passing through a doubly-refracting substance, will not be divided again on passing through another doubly-refracting surface, and there is a certain angle for every substance which is not metallic, and is capable of reflecting ordinary light, at which the ray of light which has suffered double refraction cannot be reflected. A ray of

light which has acquired these two properties, is called *polarized light*. Light may be polarized not only by passing through a doubly-refracting substance, but also by being reflected at a particular angle by a non-metallic reflector, or by being refracted at a particular angle through parallel plates of a transparent substance, which does not possess the property of double-refraction.

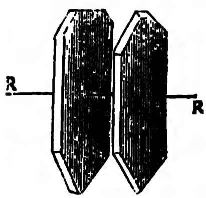


Fig. 388.

Tourmaline, especially the green and brown transparent varieties, can be so prepared as to polarize light. If a crystal of tourmaline be cut into plates, parallel to any one of the faces of the hexagonal prism, or to the principal or optic axis of the crystal, ordinary light on passing through the plate of tourmaline will be doubly refracted; but one of the two rays into which the ray is split will be completely absorbed by the tourmaline, if the plate be thick enough, and the other will be transmitted. If we look through the plates of tourmaline in the position of Fig. 388. as they are cut from the crystal, we can see through them; but if they be placed across each other, as in Fig. 389, we shall not be able to see through them, where the planes of the two plates are placed in contact with each other.

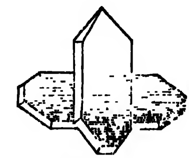


Fig. 389.

If we cause one plate of tourmaline to revolve on the other, in its own plane, through an angle of 360°, we shall find that there are two positions in which it is incapable of transmitting polarized light. A bundle of plates of glass, consisting of eight or ten similar pieces, with their edges united together with sealing-wax, or any other means, held in such a manner as to cause the light to pass through the plates obliquely, as in Fig. 390, may be substituted for the plate of tourmaline. There is also an instrument called Nicol's prism, consisting of two prisms of Iceland spar, united together with Canada balsam, at such an angle as to allow only one of the two rays of the doubly-refracted light to pass through the prism. The Nicols' prism and the plates of glass, have this advantage over the plates of tourmaline, that the light which is polarized by passing through them is not coloured.

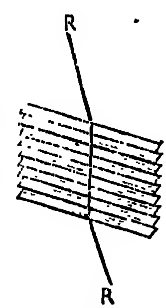


Fig. 390.

If a ray of light, which has been polarized, pass through a doubly refracting crystal, it becomes depolarized, or recovers its property of being reflecting at all angles by a non-metallic reflector, and of passing through the plate of tourmaline, the bundle of glass, or the Nicol's prism, in every position in which they may be held.

This property affords a ready test of double refraction,—if a plate, with parallel surfaces, be cleared or cut from any doubly-refracting crystal and placed between the two plates of the tourmaline, in the position, Fig. 389, in which they lose their transparency, the transparency will be restored; and if the plate be of a certain degree of thinness, depending upon the substance of which it is composed, it will appear coloured. The plate of tourmaline, through which the light in passing is polarized, is called the *polarizer*, the doubly-refracting plate the *depolarizer*, and the other plate of tourmaline through which it is seen the *analyzer*. Any non-metallic reflector, a plate of tourmaline, a bundle of glass plates, or the Nicol's prism, may be used as the *polarizer* or as the *analyzer*. Any instrument arranged with any combination of any two of these for the analyzer and polarizer, for the purpose of observing these phenomena, is called a *polariscope*.

The most convenient analyzer is a polished mahogany table or a sheet of glass lying on the table, reflecting the light of the sky falling on it through a window. If a thin plate of mica or selenite, held in the hand with its plane perpendicular to that of the table, be viewed through a plate of Tourmaline, a bundle of glass held obliquely, or a Nicol's prism, by advancing or retiring from the table its polarizing angle will soon be discovered by the brilliant tints assumed by the mica or selenite. When this angle has been determined,—if we substitute for the plate of mica a thicker slice cut from any transparent crystal belonging to the rhombohedral system, perpendicular to the principal or optic axis, or to any of the faces of the hexagonal prism, taking care to hold the slice close to the analyzer,—as we cause the analyzer to revolve round its axis we shall see a black cross, surrounded by a brilliant series of rings, exhibiting all the colours of the spectrum, as in Fig. 391, succeeded by another series of rings, intersected by a transparent cross (Fig. 392). The cleavage rhomb of calcite, or that of nitrate of soda, prepared as in Fig. 387, and viewed through the two triangular planes, will exhibit these phenomena with great brilliancy, if the thickness of the plate, or the distance between the triangular planes, be from a quarter to an eighth of an inch. The intervals between the rings are smaller as the thickness of the slice increases, or, the thickness of the slice being the same, as the doubly refracting energy of the substance from which it is cut. In crystals of the *pyramidal system*, the slice must be cut parallel to the basal pinacoids of the crystal.

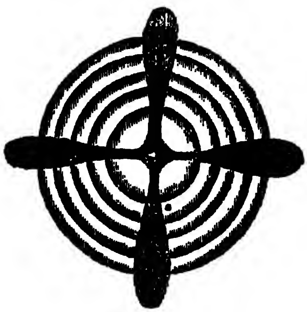


Fig. 391.

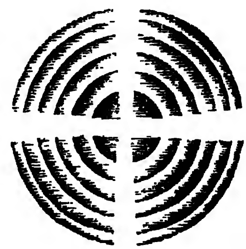


Fig. 392.

Quartz is an exception to other substances belonging to the rhombohedral system as it presents the phenomena of circular polarization. The slice of quartz, cut perpendicular to the optic axis or any of the planes of the hexagonal prism, presents in every position of the analyzer the rings without the cross, the centre of the inner ring being of one colour, which passes through all the varieties of the spectrum as the analyzer is rotated on its axis. In some specimens the colours succeed in their order from red to violet, as the analyzer is moved from right to left, and in others when it is moved from left to right.

Slices cut in proper directions from translucent crystals belonging to the *prismatic*,

Fig. 393.

Fig. 394.

oblique, and *anorthic* systems, all of which have two axes of doubled refraction, when

viewed as above, present a double system of rings round each axis; when the axes are sufficiently near to be observed at once, as in the case of nitrate of potash, the analyzer being held in the position in which it would show the black cross in the preceding case, Figs. 393 and 394 will be seen, consisting of two series of oval-coloured rings, intersected by dark brushes, which will change from the position, Fig. 393, to that in Fig. 394, as the slice of the crystal is made to rotate round its axis, while the analyzer is held fixed. If the slice of the crystal be fixed while the analyzer is made to revolve, the dark brushes will alternately vanish and re-appear, as in the crystals with one optic axis.

Arrangement and Description of Minerals.—Most modern works on Mineralogy having followed a chemical arrangement of minerals, we shall adopt that of Berzelius, as modified in the collection in the British Museum. The British Museum contains probably the finest collection of minerals in the world; it is public property, and easy of access to every student; we shall, therefore, in our description of each mineral indicate the number of the case in which it may be found. For the sake of distinguishing the specimens of one mineral from those of another, in the British Museum, the name of each mineral in the case is printed on a label with a border coloured red, green, blue, or yellow; a thin slip of wood, of the same colour as the border, surrounds all the specimens of the mineral indicated by the name on the label. Some idea of the value of the collection in the British Museum may be formed from the fact that it cost government more than £30,000, and has been greatly enriched by many valuable contributions presented to it, especially the rich private collection of the Rev. Mr. Cracherode.

In describing each mineral we shall give its name and synonymes, chemical composition in symbols, crystalline system, hardness, and specific gravity, indicated by the letters H and G; case in the British Museum; fracture, transparency, or opacity; lustre, colour, streak; brittleness, or other remarkable property; fusibility or infusibility before the blowpipe; the manner in which it is affected by acids, followed by some of its principal localities, and any observations which may be necessary as to its uses and properties.

Iron.—*Native Iron.*—Fe. **cubic.** H = 4·5 G 7·0 . . . 7·8. Case 1. Soluble in hydrochloric acid. B. infusible. *Frac.* hackly. Opaque. *Lus.* metallic. *Col.* pale steel-gray. *Str.* the same.

Native iron of terrestrial origin is mixed with a small portion of other metals, but without nickel. Dauphine, Auvergne, Brazils, Yates, United States. *Meteoric iron: Ærolite, Meteorite.*—Found in meteoric stones, with nickel, cobalt, and other metals. Siberia, Peru, Mexico, North America, Cape of Good Hope, several parts of Europe. Meteoric iron forms the substance of the rough-shaped knives of some of the Esquimaux tribes of North America. Iron is most extensively used in the arts and manufactures.

Copper.—*Native Copper.*—Cu. **cubic.** H 2·5 . . . 3·0 G 8·5 . . . 8·9. Case 1 Soluble in nitric acid. B. easily fusible. *Frac.* hackly. *Lus.* metallic. *Col.* red. *Str.* shining.

Found in veins and beds. Disseminated through rocks of all formations. Hungary, Siberia, Cornwall, Waterford, Mansfield, Kaursdorf, Chessy, Spain, Fahlun, North America, Cuba, Brazils, China, Japan, Nassau, Saxony. Copper, either by itself, or else in combination with other metals, is extensively used in the arts and manufactures. Copper is used for the stamping machinery of powder-mills, because it does not emit sparks.

Bismuth.—*Native Bismuth.*—Bi. **rhombohedral.** H 2·0 . . . 2·5 G 9·6 . . . 9·8. Case 1. Soluble in nitric acid. B. easily fusible. *Frac.* indistinct. Opaque. *Lus.* metallic. *Col.* reddish-silver-white.

Found in veins, in granite, gneiss, mica slate, and transition rocks. Saxony, Thuringia, Bohemia, Norway, Sweden, the Pyrenees, Connecticut, Cornwall. Bismuth enters into several alloys used in the arts, such as pewter, solder, and type metal.

Lead.—*Native Lead.*—Pb. **cubic.** H 1·5 G = 11·35. Case 1. Soluble in nitric acid. B. easily fusible. *Frac.* hackly. Opaque. *Lus.* metallic. *Col.* lead-gray. *Str.* shining.

Said to be found in lava and carboniferous limestone. Madeira; Bristol; Kenmare Ireland; Alston, Cumberland. Used extensively in the arts and manufactures.

Silver.—*Native Silver.*—Ag. **cubic.** H 2·5 — 3·0 G 10·1 — 11·0. Case 2. Soluble in nitric acid. B. easily fusible. *Frac.* hackly. Opaque. *Lus.* metallic. *Col.* white. *Str.* shining.

Found in veins, rarely in beds; in crystalline slate rocks, gneiss, mica slate, hornblende slate, granite, syenite, porphyry. Norway, Sweden, Saxony, Bohemia, Hungary, Transylvania, Siberia, the Hartz, Baden, the Tyrol, France, Peru, Mexico, Chili, Cornwall, Alva, Scotland. Used extensively in the arts and manufactures; mixed with copper in the proportion of 12½ to 1, it forms the standard silver of British coinage.

Mercury.—*Native Mercury.*—Hg. **cubic.** H·0· G 13·6. Case 2. Soluble in nitric acid. B. volatilizes. Opaque. *Lus.* bright metallic. *Col.* tin-white.

Found in cavities or crevices of rock containing cinnabar. Carniola, Spain, Bohemia, the Palatinate, the Tyrol, Carinthia, Peru, China, the Hartz.

Amalgam.—*Hydrargyret of Silver.*—Ag. Hg. **cubic.** H 3·0 — 3·5 G 13·7 — 14·1 Soluble in nitric acid. B. volatilizes. *Frac.* conchoidal. Opaque. *Lus.* bright metallic. *Col.* silver-white. *Str.* the same.

Found in beds containing mercury and cinnabar. The Palatinate, Hungary, Spain, France, Sweden. That found in the Arquero mine, in Chili, has been called *Arquerite.* Extensively used in the arts and for philosophical apparatus, and in the manufacture of chemical and pharmaceutical preparations.

Palladium.—*Native Palladium.* Pd. **cubic.** H 4·5 — 5·0 G 11·8 — 12·14. Case 2. Soluble in nitric acid. B. infusible. *Frac.* hackly. Opaque. *Lus.* metallic. *Col.* light steel gray.

Occurs in rolled grains with platina, and particles imbedded in and combined with gold. Brazils, Tilkerode in the Hartz. Does not tarnish. Has been used in the manufacture of philosophical instruments, particularly balances.

Platinum.—*Native Platina.*—Pt. **cubic.** H 4·0 — 4·5 G 17·3 — 18·94. Case 2. Soluble only in nitro-muriatic acid. B. infusible. *Frac.* hackly. Opaque. *Lus.* metallic. *Col.* steel gray. *Str.* the same, bright. Ductile.

Found with gold in veins of quartz, in syenite, and in alluvial sand. The Ural, Brazils, St. Domingo, Borneo, the Rhone, North Carolina. Of great value in the construction of philosophical and chemical apparatus. It is used in painting on porcelain.

Osmiridium.—*Alloy of Iridium and Osmium.*—Ir. Os. **rhombohedral.** H 7·0 G 19·3 — 21·2. Case 2. Insoluble in acids. B. infusible. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* tin-white and lead-gray. *Str.* the same.

Occurs in isolated crystals and grains with gold and platinum. South America, the Ural, Borneo.

Iridium.—*Alloy of Iridium and Platinum.* Ir. Pt. **cubic.** H 6·0 — 7·0 G 22·65 — 22·80. Insoluble in acids. B. infusible. Opaque. *Lus.* metallic. *Col.* silver-white. Highly ductile.

Occurs with platinum and osmi-iridium. The Ural, Ava. Harder, heavier, and paler in colour than platinum.

Gold.—*Native Gold.*—Au. **cubic.** H 2·5 — 3·0 G 14·55 — 19·1. Case 3. Soluble in nitro-muriatic acid. B. fusible. *Frac.* hackly. Opaque. *Lus.* metallic. *Col.* gold yellow. *Str.* bright. Ductile and malleable.

Occurs in felspathic and hornblende rocks, in conglomerates, in alluvial deposits and sands of rivers, in veins of greenstone and syenitic porphyry, in veins of quartz, in seleniuret of lead; generally combined with silver—when the proportion is considerable, it is called Electrum. Hungary, Transylvania, Mexico, Peru, and New Spain; California, Brazils, North Carolina, Australia, St. Domingo, Bohemia, Africa, Thibet, China, Java, Borneo, Sumatra, the Hartz, Danube, Rhine, Wicklow, Perthshire, Cornwall. The most ductile and flexible of all metals; extensively used for coinage, articles of luxury, and in the arts.

Tellurium.—*Native Tellurium.*—Te. **rhombohedral.** Case 3. H 2·0 — 2·5 G 6·1 — 6·3. Soluble in nitric acid. B. easily fusible. Opaque. *Lus.* metallic. *Col.* tin-white. *Str.* the same.

Occurs in a sandstone rock. Faceby, Transylvania.

Tetradymite.—*Tellurwismuth, Bornine, Molybdena-silver, Sulpho-telluret of Bismuth.* **Rhombohedral.** Case 3. H 1·0 — 1·5 G 7·4 — 7·5. Soluble in nitric acid. B. easily fusible. Opaque. *Lus.* metallic. *Col.* bright steel-gray. *Str.* the same.

Occurs in conglomerate. Schoubkan in Hungary, Deutsch Pilsen, near Grard.

Petzite.—*Hessite, Tellur Silber, Telluret of Silver.*—Ag. Te. **cubic.** Case 3. H 2·5 . . . 3·0 G 8·31 — 8·83. Soluble in hot nitric acid. B. volatilizes. *Frac.* even. Opaque. *Lus.* metallic. *Col.* steel-gray. *Str.* the same. Malleable.

Occurs with iron and copper pyrites in talk-slate. Siberia, Transylvania.

Nagyagite.—*Black or Foliated Tellurium. Auro-plumbiferous telluret.*—Pb. Te. Au. **pyramidal.** Case 3. H 1·0 — 1·8 G 7.0 — 7·2. Soluble in nitric acid. B. easily fusible. Opaque. *Lus.* metallic. *Col.* blackish lead-gray. *Str.* the same.

Occurs in veins with quartz. Nagyag and Offenbanya, Transylvania. Prized for the gold it contains.

Altaite.—*Telluret of Lead.*—Pb. Te. **cubic,** H 3·0 — 3·5 G 8·15. Soluble in nitric acid. B. fusible. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* tin-white. *Str.* the same.

Found with petzite in Sawodinski mine, in the Altai.

Sylvanite.—*Graphic and Yellow Tellurium, Schrift-erz, Mullerine.*—Te. Pb. Au. **prismatic.** Case 3. H 1·5 — 2·0 G 7·99 — 8·33. Soluble in nitric acid. B. fusible. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* steel-gray. *Str.* the same.

Found in porphyry. Offenbanya and Nagyag, Transylvania. A very rare mineral.

Antimony.—*Native Antimony*—Sb. **rhombohedral.** H 3·0 — 3·5 G 6·6 — 6·7. Case 3. Soluble in nitro-muriatic acid. B. easily fusible. Opaque. *Lus.* metallic. *Col.* tin-white. *Str.* the same.

Occurs in veins in crystalline rocks. Sahlberg in Sweden, Allemont in Dauphine, Przibram, in Bohemia, Andreasberg in the Hartz. Used as an alloy to harden the softer metals, particularly type metal; it is also used for some pharmaceutical preparations.

Antimonsilber.—*Antimonial Silver.*—Ag^4 Sb. **prismatic.** H 3·5 G 9·4 — 9·8. Case 3. Soluble partially in nitric acid. B. easily fusible. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* silver white. *Str.* the same.

Occurs in veins in granite, porphyry, and crystalline slate rocks. Andreasberg in the Hartz, Guadal canal in Spain, Allemont in France, Mexico. A rare mineral, highly valuable for extracting silver, when found in sufficient quantity.

Breithauptite.—*Nickel Antimonial.*—Ni^2 Sb. **rhombohedral.** H 5·0 G 7·54. Soluble in nitro-muriatic acid. B. volatilizes. *Frac.* uneven-conchoidal. Opaque. *Lus.* metallic. *Col.* light copper-red. *Str.* reddish-brown. Brittle.

Occurs with ores of cobalt at Andreasberg in the Hartz.

Arsenic.—*Native Arsenic.*—As. **rhombohedral.** H 3·5 G 5·7 — 5·8. Case 4. With nitric acid changes to arsenious acid. B. easily fusible, on charcoal volatilizes. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* tin-white. *Str.* the same. Brittle.

Occurs in veins, seldom in beds, in crystalline slate rocks. The Hartz, Saxony, Baden, Bohemia, Transylvania, the Banat, Dauphine, Alsace, Norway. A virulent poison, it is used in metallurgical processes and in the manufacture of glass and colours.

Kupfernickel.—*Copper Nickel, Arseniate of Nickel.*—Ni^2 As. **rhombohedral.** H 5·5 G 7·2 — 7·8. Case 4. Soluble in nitro-chloric acid. B. fusible. *Frac.* conchoidal. Opaque. *Lus.* metallic. *Col.* copper-red. *Str.* brownish-black. Brittle.

Occurs in veins, seldom in beds, in granite, clay, slate, and transition rocks. Saxony, Bohemia, Thuringia, Hessia, the Hartz, Baden, Dauphine, Styria, the Banat, Spain, Connecticut, Cornwall, Linlithgowshire. Distinguished from native copper by its brittle nature, and the green deposit it forms in nitric acid.

Rammelsbergite.—*White Arsenical Nickel.*—Ni. As. **cubic.** H 5·5 G 6·43 — 6·73. Case 4. Soluble in nitric acid. B. easily fusible. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* tin-white. Brittle.

Found at Schneeberg in Saxony, Richelsdorf in Hessia, Kamsdorf near Saalfield.

Chloanthite.—*White Nickel.*—Ni. As. **prismatic.** H 5·5 G 7·09—7·18. Opaque. *Lus.* metallic. *Col.* tin-white.

Found at Riechelsdorf and Schneeberg.

Smaltine.—*Tin-white Cobalt, Arsenical Cobalt.*—Co. As. **cubic.** H 5·5 G 6·3 — 6·6. Case 4. Soluble in nitric acid. B. easily fusible. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* tin-white. *Str.* grayish-black.

Found in veins in slate rocks. Saxony, Bohemia, Hessia, Styria, Hungary, Piedmont, Cornwall. Distinguished from native bismuth and copper nickel by its perfect cleavage, inferior hardness, and reddish tinge. Roasted to drive off the arsenic, and finely powdered, it affords a blue colour for painting porcelain, &c.; with silex and potash it produces smalt.

Safflorite.—*Cobalt Arsenical, Chathamite, Iron Cobalt.*—Co. As. and Fe. As. **cubic.** H 5·5 G 6·92 — 7·3. Soluble in nitric acid. *Frac.* uneven. *Col.* light steel-gray.

Found in veins traversing primitive rocks. Schneeberg.

Skutterudite.—*Modumite, Hard white Cobalt.*—$Co.^2$ $As.^3$ **cubic.** H 6·0 G 6·74 — 6·84. Case 4. Soluble in nitric acid. B. easily fusible. *Frac.* conchoidal. Opaque. *Lus.* metallic. *Col.* tin-white.

Found in mica state, at Skutterud in Norway.

Lolingite.—*Arsenical Pyrites, Leucopyrite.*—$Fe.^4\ As.^3$ **prismatic.** H 5·5 G 7·0 — 7·3. Soluble in nitric acid, partially. B. fusible. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* silver white. *Str.* grayish-black.

Found in veins in clay slate, in beds of chalybite, and in serpentine. Andreasberg, Carinthia, Styria, Silesia, Norway. The accidental admixture of silver renders some of the varieties of this species useful as an ore of that metal. It is employed in the manufacture of white arsenic and of realgar. Sometimes it contains a small portion of gold.

Placodine.—$Ni.^4$ As. **oblique.** H 5·0 — 5·5 G 7·99 — 8·06. Soluble in nitric acid. B. easily fusible. Opaque. *Lus.* metallic. *Col.* between bronze-yellow and copper-red. *Str.* black. Brittle.

Found at Müsen in Siegen.

Domeykite.—*Arseniuret of Copper, Condurrite.*—$Cu.^6$ As. H 3·5 G 4·20 — 4·29. Case 4. Not soluble in hydro-chloric acid. B. easily fusible. Opaque. *Lus.* metallic. *Col.* tin-white.

Found in veins in porphyritic mountains. Peru, Chili, Cornwall.

Diamond.—C. **cubic.** H = 10·0 G — 3·5 — 3·6. Case 4. Insoluble in acids *Frac.* conchoidal. Transparent-translucent. *Lus.* adamantine. *Col.* colourless, white, gray, brown, green, yellow, red, blue, rarely black. *Str.* gray.

Found in quartz, conglomerate, in strata of clay and sand containing an iron oxide, in alluviums, and in a micaceous sandstone. The Deccan, Malacca, Borneo, Celebes, Java, Brazils, Mexico, the Ural, North Carolina, Georgia. The most valued of all the gems. Employed for cutting glass, and its powder for cutting and polishing hard gems and stones.

Graphite.—*Plumbago, Carburet of Iron.*—C. **rhombohedral.** H 1·0 — 2·0 G 1·8 — 2·1. Case 4. Insoluble in acids. B. infusible. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* iron-black, dark steel gray. *Str.* black, shining.

Found in beds in gneiss, trap, and in the coal formation. Norway, Bavaria, the Pyrenees, North America, Austria, Styria, Bohemia, Moravia, Cumberland, Aberdeenshire, Kilkenny, Ayrshire, Spain, Ceylon, the Brazils, Massachusetts. Used for the manufacture of pencils and crucibles; also to diminish friction in machines.

Anthracite.—*Glance Coal.* H 2·0 — 2·5 G 1·3 — 1·75. Case 4. *Frac.* conchoidal. *Lus.* vitreous or waxy. *Col.* black. *Str.* black. Brittle.

Found in several parts of the Alps, the Pyrenees, France, Pennsylvania, Massachusetts, Bohemia, Silesia, Saxony, Staffordshire, Brecknockshire, Carmarthenshire, Pembrokeshire, Kilmarnock, and Kilkenny. Used as fuel for furnaces, and in the manufacture of metals.

Selenium.—Se. Case 4. H 2·0 G 4·3. *Frac.* conchoidal. Translucent. *Lus.* vitreous. *Col.* pale dull red.

Found incrusting sulphur in Sicily, Mexico.

Berzeline.—*Seleniuret of Copper.*—$Cu.^2$ Se. Case 4. Crystalline. *Lus.* metallic. *Col.* silver-white. *Str.* shining. Soft and malleable.

Found coating calcite at Skrickerum, Sweden, rarely in the Hartz.

Eukairite.—*Seleniuret of Silver and Copper.* $Cu.^2$ Se. + Ag. Se. Case 4. Soluble in hot nitric acid. B. fusible. Crystalline. Opaque. *Lus.* metallic. *Col.* lead-gray. *Str.* shining. Soft.

Found in serpentine at Skrickerum, Sweden.

Naumannite.—*Seleniuret of Silver.*—Ag. Se. **cubic.** H 2·4 G 8·0. Soluble in concentrated nitric acid. B. fusible. Opaque. *Lus.* metallic. *Col.* iron-black. *Str.* same. Malleable.

Found in narrow veins in diabase at Tilkerode in the Hartz.

Clausthalite.—*Seleniuret of Lead.*—Pb. Se. **cubic.** Case 4. H 2·5 — 3·0 G 8·2 — 8·8. Soluble in nitric acid partially. B. volatilizes. Opaque. *Lus.* metallic. *Col.* Lead-gray. *Str.* gray.

Found in transition rocks in the Hartz and Saxony.

Lerbachite.—*Seleniuret of Lead and Mercury.*—Pb. Se. and Hg. Se. Case 4. **Cubic.** Soft. G 7·3. Opaque. *Lus.* metallic. *Col.* lead-gray. *Str.* black.

Found in transition rocks in the Hartz.

Zorgite.—*Seleniuret of Lead and Copper.*—Pb. Se. with Cu. Se. Case 4. H 2·5 G 7·0 — 7·5. B. volatilizes. *Frac.* conchoidal. Opaque. *Lus.* metallic. *Col.* light lead gray, grass-yellow. *Str.* darker than colour.

Found in transition rocks and in a vein in clay slate. The Hartz and Thuringia.

Riolite.—Ag. $Se.^2$ **rhombohedral.** Colour lead-gray. Very malleable.

Found in Tasco in Mexico.

Onofrite.—*Seleniuret of Mercury.*—Hg. Se. with Hg. S. Case 4. H 2·5. *Lus.* metallic. *Col.* blackish, lead-gray. *Str.* shining.

Found massive in veins at San Onofre, Mexico.

Sulphur.—S. **prismatic.** H 1·5 — 2·5 G 2·0 — 2·1. Case 5. *Frac.* conchoidal, uneven. Transparent. Translucent on the edges. *Lus.* resinous, inclining to adamantine. *Col.* sulphur-yellow, passing into red-brown, gray. *Str.* sulphur, yellow-white.

Found in mica slate, lime-stone, metallic veins, beds of gypsum, sandstone, in alluvium, as a volcanic sublimate, and a deposit from hot springs, Anito, Hungary, the Black Forest, Sicily, Tuscany, Spain, Cracow, Hanover, Greenland, Thuringia, Naples, Ætna, Iceland, Java, Teneriffe, Bourbon. Used in the manufacture of gunpowder, sulphuric acid, cinnabar, and various pharmaceutical preparations.

Alabandine.—*Sulphuret of Manganese, Hexahedral Glance Blende.*—Mn. S. **cubic.** H 4·0 — G 3·95 — 4·01. Case 5. *Frac.* uneven, imperfect, conchoidal. Opaque. *Lus.* metallic, imperfect. *Col.* iron-black. *Str.* dark-green. B. fusible. Soluble in hydrochloric acid.

A rare mineral, found in veins. Nagyag, Transylvania, and in Mexico.

Hauerite.—Mn. S^2. **cubic.** H 4·0 — G 3·46. Case 5. *Lus.* adamantine. *Col.* dark reddish-brown. *Str.* brownish-red

Found in clay with gypsum, and sometimes with sulphur. Kalinka, Hungary.

Blende.—*Sulphuret of Zinc, Dodecahedral Garnet Blende, Black Jack of Miners.*—Zn. S. **cubic.** H 3·5 — 4·0 G 3·9 — 4·2. Case 5. *Frac.* conchoidal. *Lus.* adamantine. *Col.* green, yellow, red, brown, and black. Transparent. B. fusible with difficulty. Soluble in powder in concentrated nitric acid, with exception of the sulphurs.

Widely diffused in veins and beds, in crystalline slate and transition rocks. Hungary, Transylvania, Bohemia, Saxony, the Hartz, Sweden, Derbyshire, Flintshire, Cornwall, Perthshire, Leadhills, and Lanarkshire. Distinguished from the varieties of galena, garnet, and tin, which it resembles by the facility with which it yields to the knife. Of little value as an ore of zinc, from the difficulty of extracting that metal from it.

Pyrite.—*Iron Pyrites, Sulphuret of Iron, Hexahedral Iron Pyrites.* Fe. S^2. **cubic.** H 6·0 — 6·5 G 4·9 — 5·1. Case 6. *Frac.* conchoidal, uneven. Opaque. *Lus.* metallic. *Col.* brass-yellow, gold-yellow, brown. Brittle. B. fusible. Partly soluble in nitric acid. Some varieties contain a small quantity of gold.

A very common mineral, universally diffused in beds and veins of the most different formations. Elba, Piedmont, Saxony, Bohemia, Hungary, Norway, Sweden, Dauphine, Derbyshire, Cornwall, &c. Used in the manufacture of sulphur, sulphate of iron, and sulphuric acid. Distinguished from copper pyrites by being too hard to be cut by a knife; from the ores of silver by its pale bronze colour, and hardness and difficulty of fusion. Gold is sectile, malleable, and does not give off a sulphur odour before the blow-pipe.

Marcasite.—*White Iron Pyrites. Prismatic Iron Pyrites.*—Fe. S^2 **prismatic.** H 6·0 — 6·5 G 4·65 — 4.9. Case 6. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* pale bronze-yellow, sometimes inclining to green or gray. *Str.* dark greenish-gray. Brittle.

Not so common as pyrite, and not found in the older rocks. Saxony, Bohemia, Hessia, the Hartz, Condé, Cornwall, Derbyshire. Used for the same purposes as pyrite.

Pyrrhotine.—*Rhombohedral or Magnetic Iron Pyrites.* 5 Fe. S + $Fe.^2 S^3 = Fe.^7 S^8$ **rhombohedral.** H 3·5 — 4·5 G 4·6 — 4·7. Case 6. *Frac.* conchoidal. Opaque. *Lus.* metallic. *Col.* brass-yellow. *Str.* grayish-black. Feebly magnetic. Brittle.

Occurs principally in beds in the older rocks, and sometimes in meteorites. The Hartz, Bavaria, Saxony, Silesia, Cornwall, Argyleshire, and Galloway.

Linneite.—*Sulphuret of Cobalt. Isometrical Cobalt-kies.*—Co. S + $Co.^2 S^3$ **cubic.** H 5·5 G 4·8 — 5·0. *Frac.* conchoidal-uneven. Opaque. *Lus.* metallic. *Col.* silver-white, inclining to steel-gray. *Str.* blackish-gray. Brittle. B. fusible. Partly soluble in warm nitric acid.

Found in Sweden in beds of gneiss.

Syepoorite.—*Sulphuret of Cobalt.*—Co. S. *Col.* steel-gray, inclining to yellow.

Found in Syepoor, in Hindostan.

Millerite.—*Sulphuret of Nickel. Nickel Pyrites. Native Nickel.*—Ni. S. **rhombohedral.** H 3·5 G 5·26 — 5·30. Case 6. Opaque. *Lus.* metallic. *Col.* brass-yellow. *Str.* bright. B. easily fusible. Soluble in nitro-muriatic acid. Green.

Occurs in cavities, and dispersed among the crystals of other minerals. Bohemia, Saxony, Andreasberg, and Cornwall.

Eisennickelkies.—2 Fe. S + Ni. S. **cubic.** H 3·5 — 4·0 G 4·6. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* light pinchbeck-brown. *Str.* rather darker. Brittle.

Found in crystalline masses with towanite in amphibole, Norway.

Gersdorffite.—*Disomose. Arsenical Nickel.*—Ni. S^2 + Ni. As^2 or 2 Ni. S + Ni. As^2 **cubic.** H 5·0 — 5·5 G 6·1 — 6·13. Case 6. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* Light lead-gray. *Str.* grayish-black. Brittle. B. fusible. Partially soluble in nitric acid.

The Hartz, Sweden, Hungary, Spain, and the Brazils.

Ullmanite.—*Nickeliferous Gray Antimony. Hartmannite.*—Ni. Sb + Ni. S^2 **cubic.** H 5·0 — 5·5 G 6·2 — 6·55. Case 10. Opaque. *Lus.* metallic. *Col.* gray.

Str. grayish-black. Brittle. B. fusible. Partially soluble in nitro-muriatic acid, forming a green solution.

Found in iron-stone veins. Nassau, Prussia, and the Hartz.

Grunauite.—*Saynite. Nickel Bismuth Glance. Bismuthiferous Sulphuret of Nickel.* **cubic.** H 4·5 G = 5·13. Opaque. *Lus.* metallic. *Col.* light steel-grey. *Str.* dark gray. Brittle. B. fusible. Green solution in nitric acid.

Found in veins. Bohemia and Cornwall.

Greenockite.—*Sulphuret of Cadmium.* Cd. S. **rhombohedral.** H 3·8 G 4·8 — Case 6. Translucent. *Lus.* adamantine. *Col.* yellow. *Str.* orange. Soluble in warm hydrochloric acid.

Occurs in crystals in porphyritic amygdaloidal trap, at Bishopton, in Renfrewshire.

Redruthite.—*Vitreous Copper. Prismatic Copper Glance.*—$Cu.^2$ S. **prismatic.** H 2·5 — 3·0 G 5·5 ... 5·8. Case 7. *Frac.* conchoidal. Opaque. *Lus.* metallic. *Col.* blackish lead-gray. *Str.* the same, shining. Very sectile. B. easily fusible. Blue solution in warm nitric acid.

Found in beds and veins in bituminous copper slate, iron stone and clay slate. Silesia, the Hartz, Sweden, Norway, North America, Peru, Mexico, Cornwall, Yorkshire, Ayrshire, the Orkneys, and Shetland. $Cu.^2$ S. formed by the fusion of copper glance, or of copper and sulphur in the same proportions, can be obtained in octahedral crystals; this substance is therefore dimorphous. It is a rich and highly valuable ore of copper.

Covelline.—*Kupferindig. Indigo Copper. Blue Copper.*—Cu. S. **rhombohedral.** H 1·5 — 2·0 G 3·8 — 3·82. Case 7. Opaque. *Lus.* resinous. *Col.* indigo-blue. *Str.* black, shining. Sectile. B. fusible. Soluble in nitric acid.

Found in Thuringia, Salzburg, Poland, Vesuvius.

Tennantite.—*Dodecahedral dystome Glance.*—4 (Fe, 2Cu.) S + As. S^3 **cubic.** H 4·0 G 4·3 — 4·5. Case 7. Opaque. *Lus.* metallic. *Col.* blackish lead-gray—iron-black. *Str.* dark reddish-gray. Brittle. B. fusible.

In veins in granite and clay slate. Redruth, and St. Day, in Cornwall.

Bornite.—*Purple Copper. Variegated Copper. Octahedral and Hepatic Copper Pyrites. Buntkupfererz. Erubescite.*—3 $Cu.^2$ S + $Fe.^2$ S^3 **cubic.** H 3·0 G 4·9 — 5·1. Case 7. *Frac.* conchoidal-uneven. Opaque. *Lus.* metallic. *Col.* between copper-red and pinchbeck-brown . *Str.* grayish-black. Rather sectile. B. fusible. Partially soluble in concentrated hydrochloric acid.

Found in beds and veins of the older rocks. The Banat, Norway, Thuringia, Silesia, Siberia, Greenland, Sweden, North America, Saxony, the Hartz, Cornwall. A valuable mineral for extracting copper.

Cubane.—$Cu.^2$ S $Fe.^2$ S^3 + 2 Fe S or Cu. S + $Fe.^2$ S^3 **cubic.** H 4·0 G 4·026 — 4·042. Opaque. *Lus.* metallic. *Col.* brass-yellow. *Str.* black. B. fusible.

Found at Bacaranao in Cuba.

Towanite.—*Pyramidal Copper Pyrites. Yellow Copper Ore. Chalkopyrite.*— $Cu.^2$ S + $Fe.^2$ S^3. **pyramidal.** H 3·5 — 4·0 G 4·1 — 4·3. Case 7. *Frac.* conchoidal. Opaque. *Lus.* metallic. *Col.* brass-yellow. *Str.* greenish-black. Slightly brittle. B. fusible. Soluble partially in nitro-muriatic acid. It sometimes contain, traces of silver or gold.

Occurs in beds and veins with several other minerals. Saxony, Bohemia, Norway

Sweden, the Hartz, Cornwall, Anglesea, Derbyshire, Cumberland, Perthshire, Shetland, Wicklow, Hungary, Siberia, North and South America, Africa, Japan. An important ore of copper. Also used in the manufacture of blue vitriol, or sulphate of copper.

Patrinite. — *Plumbo cupriferous sulphuret of Bismuth. Nadelerz Needle Ore Arikinite. Aciculite*—($3Cu.^2$ S + Bi. S^3) + 2 ($Pb.^3$ S + Bi. S^3) **prismatic.** H 2·0 — 2·5 G 6·75. Opaque. *Lus.* metallic. *Col.* Blackish lead-gray. *Str.* blackish-gray. Slightly brittle. B. easily fusible. Partially soluble in nitric acid.

Imbedded in quartz, associated with gold. Beresow in Siberia.

Stromeyerite.—*Sulphuret of Silver and Copper. Argentiferous Copper Glance.*—$Cu.^2$ S + Ag. S **prismatic.** H 2·5 — 3·0 G 6·255. Case 10. *Frac.* conchoidal. Opaque. *Lus.* metallic. *Col.* blackish lead-gray. *Str.* the same, shining. Perfectly sectile. B. fusible. Partially soluble in nitric acid.

A rare mineral. Schlangenberg in Siberia, Chile, Silesia.

Galena.—*Sulphuret of Lead, Hexahedral Lead Glance, Blue Lead.*—Pb S, **cubic.** H 2·5 G 7·4 . . . 7·6. Case 8. B. fusible. Soluble, partially in nitric acid. *Frac.* conchoidal. Opaque. *Lus.* metallic. *Col.* lead-gray. *Str.* the same. Rather sectile.

Occurs very abundantly in rocks of the most different formations. Saxony, Bohemia, the Hartz, Hungary, France, Norway, Sweden, Spain, Silesia, North America, Greenland, Cumberland, Durham, Northumberland, Flintshire, Wales, several places in Scotland. This is the ore which yields most of the lead which is produced; it sometimes contains a small quantity of silver, which is extracted from it. Galena reduced to powder, or the litharge produced from it, is used for glazing coarse pottery.

Steinmannite.—*Octahedral Lead Glance.*—Pb S, Sb S^3, **cubic.** H 2·5. G 6·83. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* lead-gray. *Str.* gray, shining. Sectile. B. fusible.

Found at Pezibram, in Bohemia, with silver, blende, pyrite, and quartz.

Bismuthine.—*Sulphuret of Bismuth, Prismatic Bismuth Glance.*—Bi S^3 **prismatic.** H 2·0 G 6·4 — 6·5. Case 9. *Frac.* imperfect, conchoidal. Opaque. *Lus.* metallic. *Col.* lead-gray. *Str.* the same. B. easily fusible. Soluble easily in nitric acid.

Rather a rare mineral. Sweden, Saxony, Bohemia, Norway, Siberia, Cornwall, and Cumberland.

Stannine.—*Sulphuret of Tin, Tin Pyrites.*—($2Cu^2$ S + Sn S^2) + (2Fe S + Sn S^2) **cubic.** H 4·0 G = 4·3 — 4·51. Case 9. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* steel-gray, inclining to bronze-yellow. *Str.* black. Brittle. B. fusible. Blue solution in nitric acid.

Found in veins in Bohemia and Cornwall. Sometimes called bell-metal ore, from its yellowish tinge; distinguished from copper pyrites, and fahlerz by its colour and black streak.

Cinnabar.—*Sulphuret of Mercury, Peritomous Ruby Blende.*—Hg S **rhombohedral.** H 2·5 — G 8·0 — 8·2. Case 9. Semitransparent, translucent on the edges. *Lus.* adamantine. *Col.* cochineal-red, passing into lead-gray and scarlet-red. *Str.* scarlet. Sectile. Soluble in nitro-muriatic acid.

In beds and veins. Spain, Syria, Bohemia, Saxony, the Hartz, the Ural, Mexico, Peru, China, Japan. It is the most abundant and important ore of mercury. *Vermilion* is pure cinnabar, and is used as a pigment and in colouring red sealing-wax.

Argentite.—*Sulphuret of Silver, Henkelite, Hexahedral Silver Glance.*—Ag S **cubic.** H 2·0 — 2·5 G 7·196. Case 10. *Frac.* uneven, hackly. Opaque. *Lus.* metallic. *Col.* blackish, lead-gray. *Str.* shining. Malleable. B. fusible. Soluble partially in concentrated nitric acid.

Found in veins. Saxony, Norway, Bohemia, Hungary, the Hartz, Spain, Sardinia, Siberia, Mexico, Peru, Cornwall. A valuable silver ore.

Sternbergite. —*Flexible Silver, Prismatic Eutom Glance.* — Ag S + $2Fe^2$ S^3 **prismatic.** H 1·0 — 1·5 G 4·215. Case 10. *Lus.* metallic. *Col.* pinchbeck-brown. *Str.* black. Sectile. B. fusible. Decomposible by nitro-muriatic acid, leaving sulphur and chloride of silver.

Found in veins with pyrargyrite and argentite. Bohemia and Saxony.

Antimonite.—*Sulphuret of Antimony, Gray Antimony, Prismatic Antimony Glance.*—Sb S^3 **prismatic.** H 2·0 G 4·6 — 4·7. Case 10. *Frac.* conchoidal, imperfect. Opaque. *Lus.* metallic. *Col.* lead-gray. *Str.* lead-gray. Sectile. B. fusible. Soluble in warm hydrochloric acid.

Found in veins in granite and slate rocks. Hungary, Transylvania, Saxony, the Hartz, France, Tuscany, Cornwall, Spain, North and South America. Almost the only ore of antimony found in sufficient quantities for commercial purposes.

Plumosite.—*Capillary Sulphuret of Antimony, Federerz.* — 2 Pb S + Sb S^3 H 3·0 G 5·7 — 5·9. Case 10. Opaque. *Lus.* metallic, feeble. *Col.* blackish lead-gray. Sectile.

Found in flexible, fine, capillary crystals in veins with antimonite, galena, &c. The Hartz.

Bournonite. —*Plumbo-cupriferous Sulphuret of Antimony, Diprismatic Copper Glance.*—(3 Cu^2 S + Sb S^3) + 2(3 Pb S + Sb S^3) **prismatic.** H 2·5 — 3·0 G 5·70 — 5·87. Case 11. *Frac.* conchoidal, uneven. Opaque. *Lus.* metallic. *Col.* steel-gray *Str.* the same. Brittle. B. fusible. Partially soluble in nitric acid.

Found in veins in slate rocks. The Hartz, Saxony, Transylvania, Hungary, Savoy, France, Piedmont, Cornwall, Devonshire, Siberia, Mexico. Used as a copper ore when found in sufficient quantity.

Wolchite.—*Antimonial Copper Glance.*—**prismatic.** H 3·0 G 5·7 — 5·8. *Frac.* imperfect, conchoidal. Opaque. *Lus.* metallic. *Col.* blackish lead-gray. *Str.* the same. Brittle. B. fusible.

Found in a bed of chalybite at St. Gretrand in Carinthia.

Wolfsbergite.—*Sulphuret of Copper and Antimony.*—Cu^2 S + Sb S^3 **prismatic.** H 3·5 G 4·748. *Frac.* conchoidal, uneven. Opaque. *Lus.* metallic. *Col.* lead-gray, iron-black. *Str.* black, dull. B. fusible.

Found with quartz and other minerals at Wolfsberg in the Hartz.

Boulangerite.—*Sulphuret of Antimony and Lead, Embrithite.*—3 Pb S + Sb S^3 H 3·0 G 5·96 — 6·0. Case 11. Opaque. *Lus.* metallic. *Col.* blackish lead-gray. *Str.* darker. Slightly brittle. B. fusible. Soluble in warm hydrochloric acid.

Found in granular or fibrous masses. France, Sayn, Lapland, Siberia.

Schulzite.—*Geokronite, Kilbrickenite.*—5 Pb S + Sb S^3 **prismatic.** H 2·5 — 3·0 — G 5·8 — 6·54. *Frac.* conchoidal, even. Opaque. *Lus.* metallic. *Col.* lead-gray. *Str.* the same. Brittle. B. easily fusible.

Found in galena. Spain, Tuscany, Sweden, Ireland.

Zinckenite.—*Rhombohedral Dystom Glance.*—$Pb\,S + Sb\,S^3$ **prismatic.** H 3·0 — 3·5 G 5·30 — 5·35. Case 11. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* dark steel-gray. *Str.* the same. Slightly brittle. B. fusible. Decomposed by warm hydrochloric acid, forming chloride of lead.

Found in a vein with antimonite and quartz at Wolfsberg, in the Hartz, and near St. Trudport in the Black Forest.

Jamesonite.—*Axotomous Antimony Glance.*—$3\,Pb\,S + 2\,Sb\,S^3$ **prismatic.** H 2·0 2·5 G 5·564 — 5·616. Case 11. Opaque. *Lus.* metallic. *Col.* steel-gray. *Str.* the same. Ductile. B. easily fusible. Decomposed by warm hydrochloric acid, forming chloride of lead.

Found sometimes with bournonite. Cornwall, Estramadura, Hungary, France, Siberia, Brazils.

Berthierite.—*Haidingerite, Sulphuret of Antimony and Iron.*—$Fe.\,S + Sb\,S^3$ H 2·0 . . . . 3·0 G 4·0 — 4·3. Case 11. *Frac.* uneven. *Lus.* metallic. *Col.* iron-black. B. fusible. Soluble in hydrochloric acid.

Found in crystalline masses in gneiss. Auvergne, La Creuse, Saxony, Hungary. Yields antimony of such inferior quality that the manufacturers cannot use it.

Stephanite.—*Brittle Sulphuret of Silver, Prismatic Melane Glance, Black Sulphuret of Antimony and Silver.*—$6\,Ag\,S + Sb\,S^3$ **prismatic.** H 2·5 G 6·2 — 6·3. Case 11. *Frac.* conchoidal, uneven. Opaque. *Lus.* metallic. *Col.* iron-black. *Str.* the same. Sectile. B. fusible.

Found in veins in crystalline slate rocks, transition rocks, trachyte. Saxony, Bohemia, Hungary, the Hartz, Mexico. This is a valuable ore of silver.

Proustite.—*Red Silver, Ruby-blende.*—$3\,Ag\,S + As\,S^3$ **rhombohedral.** H 2·0 — 2·5 G 5·5 — 5·6. Case 11. *Frac.* conchoidal, uneven. Semi-transparent. *Lus.* adamantine. *Col.* cochineal-red, carmine-red. *Str.* Aurora-red. Slightly sectile. B. easily fusible. Soluble partially in nitric acid.

Found with other minerals in veins. Saxony, Bohemia, Baden, Alsace, Dauphiné, Spain, Mexico, Peru.

Pyrargyrite.—*Red Silver, Sulphuret of Silver and Antimony, Rhombohedral Ruby-blende.* $3\,Ag\,S + Sb\,S^3$ **rhombohedral.** H 2·0 — 2·5 G 5·75 — 5·85. Case 11. *Frac.* conchoidal. Translucent on the edges. Opaque. *Lus.* adamantine. *Col.* adamantine-red, blackish lead-gray. *Str.* cochineal-red, cherry-red. Slightly sectile. B. easily fusible. Soluble partially in nitric acid.

Found in veins in crystalline slate and transition rocks, granite and trachyte. The Hartz, Saxony, Bohemia, Baden, Hungary, Mexico, Cornwall. Distinguished from red orpiment by the yellow streak of the latter and its specific gravity; from cinnabar by forming a metallic globule before the blowpipe. A valuable ore of silver.

Miargyrite.—*Hemiprismatic Ruby-blende.*—$Ag\,S + Sb\,S^3$ **oblique.** H 2·5 G 5·3 — 5·4. Case 11. *Frac.* imperfect, conchoidal. Opaque. *Lus.* adamantine. *Col.* blackish lead-gray. In thin splinters,—blood-red by transmitted light. *Str.* Cherry-red. Very sectile.

A very rare mineral, from Baünsdorf, in Saxony.

Kobellite.—*Sulphuret of Antimony, Lead, and Bismuth.*—$(3\,Fe\,S + 2\,Sb^2\,S^3) + 4\,(3\,Pb\,S + Bi^2\,S^3)$. Soft. G 6·29 — 6·32. Case 11. Opaque. *Lus.* metallic. *Col.* dark lead-gray. *Str.* black.

Found in the cobalt mine of Hvena, Sweden.

Kermes.—*Red Antimony, Prismatic Purple Blende Sulphuret of Oxide of Antimony.*—$Sb\ O^3 + 2\ Sb\ S^3$ **oblique.** H 1·5 G 4·5 — 4·6. Case 38. Faintly translucent. *Lus.* adamantine. *Col.* cherry-red. *Str.* the same. Sectile. B. fusible. Soluble in hydrochloric acid.

Found in veins in crystalline, slate, and transition rocks. Saxony, Bohemia, Hungary, Dauphiné.

Plagionite.—*Hemiprismatic Dystom Glance.*—$4\ Pb\ S + 3\ Sb\ S^3$ **oblique.** H 2·5 G 5·4. Case 12. *Frac.* imperfect, conchoidal. Opaque. *Lus.* metallic. *Col.* blackish lead-gray. *Str.* the same. Brittle. B. fusible.

Found in a vein of quartz. Wolfsberg, in the Hartz.

Feuerblende.—H 2·0 G 4·2 **oblique.** Translucent. *Lus.* pearly. Sectile and rather flexible.

Found in the Kurprinz, near Freiberg, and at Andreasberg.

Fahlerz.—*Gray Copper, Tetrahedral Copper Glance.* $(4\ Pb\ S,\ 4\ Fe\ S,\ 4\ Zn\ S,\ 4\ Cu^2\ S) + Sb\ S^3$ **cubic.** H 3·0 — 4·0 G 4·5 — 5·2. Case 12. *Frac.* conchoidal, uneven. Opaque. *Lus.* metallic. *Col.* steel-gray, iron-black. *Str.* black, dark red. Rather brittle. B. fusible. Decomposed by nitric acid.

Found in beds and veins. The Hartz, Nassau, Tyrol, Transylvania, Hungary, Bohemia, Siberia, Mexico, Chili, Peru, Cornwall, Devonshire, East Lothian. Accompanies copper pyrites, is worked as a copper ore, also occasionally for the silver it contains.

Freieslebenite.—*Sulphuret of Silver and Antimony, Peritomous Antimony Glance.*—$(Ag\ S + Sb\ S^3) + 2\ (3\ Ag\ S + Sb\ S^3)$, the Ag is sometimes replaced by Pb. **Oblique.** H 2·5 G 6·19 — 6·38. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* steel-gray. *Str.* the same. Brittle. B. fusible.

A very rare mineral, found in veins in gneiss, Freiburg in Saxony.

Orpiment.—*Yellow Sulphuret of Arsenic, Prismatoidal Sulphur.* $As.\ S^3$ **prismatic.** H 1·5 — G 3·48. Case 12. Semi-transparent, translucent on the edges. *Lus.* resinous. *Col.* lemon yellow. Sectile. Soluble in nitro-muriatic acid.

Found in beds and in veins. The Hartz, St. Gotthardt, the Tyrol, Solfatara, Vesuvius, Guadaloupe, Japan. Employed as a pigment.

Realgar.—*Red Sulphuret of Arsenic, Hemiprismatic Sulphur.*—$As.\ S^2$ **oblique.** H 1·5 G 3·556. Case 12. *Frac.* conchoidal. Semi-transparent, translucent. *Lus.* resinous. *Col.* aurora red. *Str.* orange yellow. Sectile. B. fusible. Partially soluble in hot nitro-muriatic acid.

Found in veins. Transylvania, Hungary, Bohemia, Saxony, the Hartz, Baden, Hungary, St. Gotthardt, the Tyrol, Peru, United States, Vesuvius, Ætna, Japan. Used as a pigment.

Mispickel.—*Arsenical Iron, Prismatic Arsenical Pyrites.*—$Fe\ S^2 + Fe\ As.$ **prismatic.** H 5·5 G 6·0 — 6·3. Case 12. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* silver-white. *Str.* grayish-black. Brittle. B. fusible. Soluble in nitric acid.

Found in veins and beds. Saxony, Bohemia, Silesia, Hungary, Transylvania, Sweden, Cornwall, Norway, United States. Worked as an ore of arsenic, the white oxide of commerce being principally obtained from it.

Dufrenoysite.—$2\ Pb\ S + As\ S^3$ **cubic.** G 5·549. *Frac.* uneven. Opaque. *Lus.* metallic. *Col.* steel-gray. *Str.* reddish-brown. Brittle. B. fusible. Decomposed by hot nitric acid.

Found in narrow veins in the dolomite of St. Gotthardt.

Xanthocone.—(3 Ag S + As S^5) + 2 (3 Ag S + As S^4). **rhombohedral.** H 2·0 – 3·0 G = 5·158 – 5·191. *Frac.* conchoidal, uneven. Transparent, translucent. *Lus.* adamantine. *Col.* orange yellow-brown. *Str.* the same, darker. Brittle. B. fusible.

Found in the Himmelsfürst mine near Freiberg in Saxony.

Cobaltine.—*Bright White Cobalt, Hexagonal Cobalt Pyrites, Cobalt Glance.*—Co S^2 + Co As. **cubic.** H 5·5 G 6·1 – 6·3. Case 12. *Frac.* imperfect, conchoidal, uneven. Opaque. *Lus.* metallic. *Col.* silver-white. *Str.* grayish-black. Brittle. B. fusible. Soluble in warm nitric acid.

Found in beds in crystalline rocks. Norway, Sweden, Silesia, the Banat.

Glaucodote.—R S^2 + R As where R is Co and Fe. **prismatic.** H 5·0 G = 5·975 – 6·003. Opaque. *Lus.* metallic. *Col.* dark tin-white. *Str.* black. B. fusible.

Found in veins in chlorite slate. Huasko in Chili.

Molybdenite.—*Sulphuret of Molybdena, Dirhombohedral, Eutom Glance.*—Mo S^2. **rhombohedral.** H 1·0 – 1·5 G 4·5 – 4·6. Case 12. Opaque. *Lus.* metallic. *Col.* lead-gray. *Str.* the same. Very sectile. Green solution with hot nitric acid.

Saxony, Bohemia, Sweden, Norway, France, United States, Peru, the Brazils, Cornwall, Cumberland, Westmoreland, Inverness-shire.

Voltzine.—4ZnS + ZNS. H 4·5 G 3·66. *Frac.* conchoidal, translucent on the edges. Opaque. *Lus.* pearly. *Col.* brick-red.

Found in a vein of quartz. Rosières, Puy de Dome in France, and in some zinc furnaces.

Manganite.—*Gray Oxide of Manganese, Prismatoidal Manganese Ore.*—Mn^2O^3 + HO. **prismatic.** H 3·5 – 4·0 G 4·22 — 4.34. Case 13. Opaque. *Lus.* metallic, imperfect. *Col.* dark steel-gray, brownish, black-velvet-black. *Str.* reddish-brown. Brittle. B. infusible. Soluble in hydrochloric acid.

Found in veins in porphyry, gneiss, and cavities of amygdaloidal trap. The Hartz, Thuringia, Aberdeenshire, Norway, Sweden, Nova Scotia. The purest and most beautifully crystallized ore of manganese.

Pyrolusite.—*Prismatic oxide of Manganese, Anhydrous Peroxide of Manganese.*—MnO^2. **prismatic.** H 2·0 – 2·5 G 4·7 — 5·0. Case 13. *Frac.* uneven. Opaque. *Col.* dark steel-gray, light iron-black. Brittle. B. infusible. Soluble in hydrochloric acid.

Found at Thuringia, Moravia, the Hartz, Saxony, Bohemia, Austria, Silesia, the Brazils. It is an ore of manganese most extensively worked in many countries. It derives its name from πυρ *fire*, and λουω *I wash*, on account of its property of clearing glass from its brown and green tints, a property which makes it of great value to the manufacturer. *Varvasite* is supposed to be a mechanical mixture of *pyrolusite* and *manganite.*

Polianite.—MnO^2. **prismatic.** H 6·5 — 7·0 G 4·838 — 4·880. Case 13. Opaque. *Lus.* metallic, feeble, *Col.* light steel-gray. *Str.* gray. B. infusible. Soluble in hydrochloric acid.

Found in Bohemia, Saxony, and Siegen.

Psilomelane.—*Uncleavable Manganese Ore, compact and fibrous Manganese Ore, or Black Hematite.*—**Amorphous.** H 5·0 — 6·0 G 3·7 — 4·4. Case 13. *Frac.*

even, flat, conchoidal. Opaque. *Lus.* metallic, imperfect. *Col.* bluish-black, grayish-black, dark steel-gray. *Str.* brownish-black, shining. Brittle.

The Hartz, Saxony, Styria, Siegen, Black Forest, Silesia, Bohemia, Hungary, Norway, Devonshire, Cornwall, North America. One of the most widely diffused ores of manganese; it derives its name ψιλός smooth, and μελας black, from its black colour and smooth botryoidal shapes.

Braunite.—*Brachytypous Manganese Ore.*—Mn^2O^3, **pyramidal.** H 6·0 — 6·5 G 4·8 — 4·9. Case 13. *Frac.* uneven. Opaque. *Lus.* metallic, imperfect. *Col.* dark brownish-black. *Str.* brownish-black. Brittle. B. infusible. Soluble in hydrochloric acid.

Found in veins in quartzose porphyry. Thuringia, Mannsfeld, Westphalia, Piedmont. Distinguished from other ores of manganese by its hardness.

Hausmannite. —*Pyramidal Manganese Ore, Black Manganese.*—$MnO + Mn^2O^3$, **pyramidal.** H 5·0 — 5·5 G 4·7 — 4·8. Case 13. *Frac.* uneven. Opaque. *Lus.* imperfect metallic. *Col.* brownish-black. *Str.* dark reddish-brown. B. infusible. Soluble in warm hydrochloric acid.

Found in veins in porphyry. Oehrenstock in Thuringia, Shelefield in the Hartz. Rather a scarce mineral.

Wad.—*Hydrous Oxide of Manganese, Earthy Manganese.*—**Amorphous.** H 6·5 G 2·179 — 3·700. Case 13. Opaque. *Lus.* imperfect, metallic, feeble. *Col.* clove-brown, passing into gray. *Str.* brown, shining. Very sectile, unctuous to the touch.

The Hartz, Franconia, Siegen, Nassau, Carinthia, Piedmont, Mayenne, Arriege, Cornwall, and Devonshire. Supposed to afford the colouring matter in dendritic delineations upon limestone, steatite, and other substances.

Crednerite.—*Oxide of Manganese and Copper.*—$Cu\ O + (Mn\ O + Mn^2\ O^3)$ **oblique.** H 4·5 – 5·0 G 4·89 – 5·07. *Frac.* uneven. *Lus.* metallic. *Col.* iron black. *Str.* black. Soluble in hydrochloric acid.

Found at Friedrichrode in Thuringia.

Senarmontite.—$Sb\ O^3$. **cubic.** H 2·5 — 3·0 G 5·22 — 5·30. *Frac.* uneven. lamellar. Transparent-translucent. *Lus.* resinous. Colourless. *Str.* white. B. fusible. Soluble in nitro-muriatic acid.

Found at Sensa in Algiers.

Magnetite.—*Magnetic Iron Ore, Octahedral Iron Ore, Oxydulated Iron.*—$Fe\ O + Fe^2\ O^3$. **cubic.** H 5·5 — 6·5 G 4·96 — 5·20. Case 14. *Frac.* conchoidal, uneven. Opaque. *Lus.* metallic. *Col.* iron black. *Str.* black. B. fusible with great difficulty. Soluble in warm hydrochloric acid, highly magnetic, more so than any other ore of iron.

Found in Norway, Sweden, Lapland, the Ural, the Hartz, Saxony, Bohemia, Corsica, Elba, the Savoy, Spain, New York, New Jersey, Mexico, the Brazils, East Indies, Cornwall, Wicklow. Siberia and the Hartz produce the most powerful natural magnets or loadstones. This ore is distinguished from specular iron by its streak and action on the magnet; it is a very valuable ore, the steel made from its iron being excellent in quality.

Hematite.—*Specular Iron, Red Iron Ore, Rhombohedral Iron Ore, Iron Glance, Oligiste Iron.*—$Fe^2\ O^3$. **rhombohedral.** H 5·5 — 6·5 G 5·0 — 5·3. Case 15. *Frac.* conchoidal, uneven. Opaque, very thin laminæ translucent. *Lus.* metallic. *Col.*

steel-gray, iron black. *Str.* cherry-red, reddish-brown. Brittle. B. infusible. Soluble in warm hydrochloric acid.

Found chiefly in beds and veins in the older rocks. Elba, the Alps, Saxony, Brazils, Salzburg, Cornwall, Lanarkshire, Siberia. A considerable portion of the iron produced in different parts of the globe is obtained from this ore; it requires a greater heat than some other ores, but affords an excellent metal. Ground hematite is used for polishing metals and glass, and also as a colouring substance.

Gothite.—*Prismatic Iron Ore, Hydrous Oxide of Iron, Brown hematite, Pyrrhosiderite Onegite.*—$Fe^2 O^3 + H O$. **prismatic.** H 5·0 – 5·5 G 4·12 – 4·37. Case 16. *Frac.* imperfect, conchoidal. Translucent on the edges. Opaque. *Lus.* adamantine. *Col.* yellowish-brown, reddish-brown, blackish-brown. *Str.* yellowish-brown. Brittle, B. fusible with great difficulty. Soluble in hydrochloric acid.

In veins and cavities. Clifton, Cornwall, Oberstein, Bavaria, Nassau, Saxony, Silesia, Bohemia, Hungary, Russia, Mount Sinai, Brazils. A good iron ore.

Limnite.—*Brown Hematite, Hydrous Oxide of Iron.*—$2 Fe^2 O^3 + 3 H O$ H 5·0 – 5·5 G 3·4 — 3·95. Case 16. Opaque. *Lus.* resinous. *Col.* yellowish-brown, blackish-brown. *Str.* yellowish-brown. Brittle. Soluble in warm hydrochloric acid.

Carinthia, Styria, Hungary, Saxony, Nassau, the Hartz, Black Forest, Bohemia, Silesia, the Pyrenees, Spain, Scotland, Cornwall, Siberia, Brazils, United States.

Turgite.—$2 Fe^2 O^3 + H O$. **massive.** H 5·0 G 3·56 – 3·74. *Frac.* even, conchoidal. Opaque. *Lus.* dull. *Col.* brownish-red. *Str.* blood-red. B. infusible.

Found in copper mines in the Ural and the Altai.

Cuprite.—*Red Oxide of Copper, Ruby Copper, Octahedral Copper Ore.*—$Cu^2 O$. **cubic.** H 3·5 — 4·0 G 5·89 – 6·15. Case 17. *Frac.* conchoidal, uneven. Semi-transparent, translucent on the edges. *Lus.* adamantine. *Col.* cochineal red, lead-gray. *Str.* brownish-red, shining. Brittle. B. reducible. Soluble in nitric acid, and in ammonia.

Found in beds and veins in granite and crystalline slate rocks. The Banat, Siberia, Lyons, Cornwall, Cuba, Spain, Saxony, Norway, Australia, Peru and Chili. When found in sufficient quantity one of the most valuable ores of copper.

Ice.—$H O$ **rhombohedral.** H 1·5 G 0·918 at 0° centigrade. *Frac.* conchoidal. pellucid. *Lus.* vitreous. Sectile, rather brittle.

Hexagonal prisms said to be observed in the levels of the Lorenz Gengentrum mine near Freiberg.

Irite.—$Ir O^3 + Os O^3, Cr O^3$ probably. **cubic.** = 6·056. Case 2. *Lus.* metallic. *Col.* iron black. Insoluble in acids.

In fine scales in cavities of the larger pieces of platinum, and in the ferruginous platinum sand of the Ural.

Periclase—$Mg O$. **cubic.** H 6·0 – G 3·75. Transparent. *Lus.* vitreous. *Col.* dark green. B. infusible. Soluble when in powder in acids.

Found in Monte Somma near Naples.

Brucite.—*Rhombohedral 'Kuphon Glimmer.*—$Mg O + HO$. **rhombohedral.** H 2·0 G 2·3 – 2·4. *Frac.* scarcely observable. Semi-transparent-translucent. *Lus.* pearly. *Col.* white, sometimes inclining to gray and green. *Str.* white. Sectile. B. infusible. Soluble in acids.

Found in serpentine. New Jersey, New York, Scotland, Siberia.

Wismuthocher.—*Bismuthochre, Oxide of Bismuth.*—Bi O^3. Soft. G 4·361. Case 17. *Frac.* uneven, earthy. Opaque. *Lus.* adamantine, feeble. *Col.* yellow-gray, variable. B. reducible. Soluble in nitric acid.

Found with bismuth in Saxony, Bohemia, Siberia.

Spartalite.—*Red Oxide of Zinc, Zincite, Spartalite, Red Zinc, Prismatic Zinc Ore.*—Zn O. **Rhombohedral.** H 4·0 — 4·5 G 5·43 — 5·53. Case 17. *Frac.* conchoidal, Translucent on the edges. *Lus.* adamantine; when pure colourless, usually red, inclining to yellow. *Str.* orange-yellow. Brittle. B. infusible. Soluble in nitric acid.

Found in beds with franklinite and calcite in iron mines in New Jersey and near Sparta. Also found distinctly crystallized in the iron and zinc furnaces of Silesia and Liege.

Franklinite.—*Dodecahedral Iron Ore.*—RO + R^{12} O^3 where R is Fe, Mn, or Zn, and R^1, Fe, or Mn. **cubic.** H 6·0 — 6·5 G 5·07 — 5·13. Case 17. *Frac.* conchoidal. Opaque. *Lus.* metallic. *Col.* iron-black. *Str.* dark brown. Brittle. B. infusible. Soluble in warm hydrochloric acid.

Found with spartalite and calcite in New Jersey; with calamine and smithsonite at Altenberg. A rare mineral, distinguished from magnetic iron by its streak.

Asbolane.—*Earthy Cobalt, Black Cobalt Ochre, Black Oxide of Cobalt.*—(Co O or Cu O) + 2 Mn O^2 + 4 HO. **amorphous.** H 1·0 — 1·5 G 2·2. Case 17. *Frac.* conchoidal. Opaque. *Lus.* resinous, glimmering, dull. *Col.* Bluish and brownish-black, blackish-blue. *Str.* black, shining. Sectile. B. infusible.

Found in Thuringia, Hessia, Black Forest, Lusatia, the Tyrol, Siberia, Cheshire, Howth, near Dublin. Used in the manufacture of smalt.

Pechuran.—*Pitch Blende, Uran Ochre, Uraine, Oxide of Uranium.*—U O + U^2 O^3. **cubic.** H 5·5 G 6·4 — 6·71. Case 17. *Frac.* conchoidal, uneven. Opaque. *Lus.* resinous. *Col.* pitch-black, greenish-black, grayish-black. *Str.* greenish-black. Brittle. B. infusible. Dissolves in hot nitric acid.

Found accompanying ores of silver and lead. Saxony, Bohemia, and Cornwall. A valuable ore for the porcelain painter, producing a fine orange colour, and also a black.

Minium.—*Native Minium, Red Oxide of Lead, Mennige.*—2 Pb O + Pb O^2 H 2·0 — 3·0 G 4·6. Case 18. *Frac.* earthy, even, flat, conchoidal. Opaque. *Lus.* resinous. *Col.* aurora red. *Str.* orange-yellow. B. fusible. Partially soluble in nitric acid.

Found in veins in clay slate. Anglesea, Yorkshire, Siberia; often a produce of the decomposition of other lead ores.

Cassiterite.—*Oxide of Tin, Tin Stone, Pyramidal Tin Ore.*—Sn O^2. **pyramidal.** H 6·0 — 7·0 G 6·8 — 7·0. Case 18. *Frac.* imperfect, conchoidal. Semi-transparent. Opaque. *Lus.* adamantine. *Col.* colourless, gray, yellow, red, brown-black. *Str.* light-gray, light-brown. Brittle. B. infusible. Not acted upon by acids.

Found in veins and beds. Sumatra, Siam, Pegu, Malacca, Brazils, Cornwall, Bohemia, Saxony, Silesia, Spain, France, Mexico, Chili, Sweden, Russia, North and South America. A valuable tin ore. Upwards of 4000 tons of tin are annually obtained from the mines in Cornwall. It is extensively used for covering vessels of copper and iron; also in the composition of pewter, and for mirrors. The muriate of tin is of great value to the dyer and calico printer.

Plattnerite.—*Superoxyd of Lead.*—Pb O^2. **rhombohedral.** G 9·392 — 9·448. *Frac.* uneven. Opaque. *Lus.* adamantine. *Col.* iron-black. *Str.* brown. Brittle. B. easily reduced.

Supposed to have been found at Leadhills.

Corundum.—*Rhombohedral Corundum, Corindon.*—AlO^3. **rhombohedral.** H 9·0 G 3·93 — 4·08. Case 19. *Frac.* conchoidal, uneven. Transparent, translucent on the edges. *Col.* white, colourless, red, blue, green, yellow, brown, and gray. B. infusible. Insoluble in acids.

The red varieties are called *rubies* and the blue *sapphires*, and are found in gravel and river sand in Ceylon, Pegu, the Elbe, Bohemia. and Puy in France. The other crystallized varieties are called *corundum*, and *adamantine spar* when of a brown colour, and are found in China, Ceylon, the Carnatic, Mysore, the Ural, Piedmont, Sweden, Lapland, New Jersey, Connecticut, the Rhine. The granular and massive variety called *emery* is found in Saxony, Italy, Spain, and Asia Minor. The red sapphire, or oriental ruby, when perfect in colour and transparency, and of a considerable size, almost rivals the diamond in value. Some of the blue sapphires, cut perpendicularly to the axis of the six-sided prisms, present a bright opalescent star with six rays, and are called *star sapphires.* Emery is used extensively for polishing and cutting gems, stones, and other articles.

Diaspore.—*Euklastic Disthene Spar.*—Al O^3 + H O. **prismatic.** H 5·5 G 3·30 — 3·43. Case 19. *Frac.* conchoidal, uneven. Transparent, translucent. *Lus.* vitreous, pearly. *Col.* colourless, white, green, blue, dark violet, yellowish-brown. *Str.* white. B. infusible.

Found in the Ural, Hungary, St. Gotthardt, Ephesus. An extremely rare mineral distinguished from *kyanite* by its superior lustre.

Hydrargillite.—Al O^3 + 3 H O. **rhombohedral.** H 2·5 — 3·0 G 2·340 — 2·387. Case 19. *Lus.* vitreous, pearly, bright. *Col.* colourless, light reddish-white. B. infusible. Soluble with difficulty in hot sulphuric acid or hydrochloric acid.

The Ural, Brazils, and Massachusetts.

Volknerite.—6 Mg O + Al^3 O^3 + 16 HO. **rhombohedral.** G 2·04. *Lus.* pearly. *Col.* white. Unctuous to the touch. B. infusible. Soluble in acids.

Found at Schischimskaja, in the Ural.

Spinelle.—*Aluminate of Magnesia, Dodecahedral Corundum.*—Mg O + Al O^3. The Mg sometimes replaced by Fe, and the Al by 2 Fe. **Cubic.** H 7·5 — 8·3 G 3·52 — 3·95. Case 19. *Frac.* conchoidal. Transparent, translucent, opaque when black. *Lus.* vitreous. *Col.* white, red, blue, green, yellow, brown, black. *Str.* white. Brittle. B. infusible. Insoluble in hydrochloric acid, partially so in sulphuric acid.

Red and *violet spinelle*, found in alluvial soil and in the sand of rivers. Ceylon, Ava, Mysore. The scarlet is called the *spinelle ruby;* the rose-red, *balas ruby;* the yellow or orange-red, the *rubicelle;* and the violet-coloured, *almandine ruby. Blue spinelle* in granular limestone and dolomite; Sweden, Finland, Moravia, and Ceylon. *Black spinelle*, called *pleonaste;* Ceylon, Bohemia, Montpellier, the Tyrol, Vesuvius, the Ural, New York. *White spinelle*, found with black garnet and green augite, at La Ricia, near Rome. *Grass-green spinelle*, called *chloro-spinelle*, in the chlorite slate of Slatoust, in the Ural. The spinelle ruby is a gem, and when well coloured and large is highly prized. Distinguished from the oriental ruby by being softer, from garnet by its lighter colour, and from red topaz, whose colour has been produced artificially, by its not possessing double refraction.

Gahnite.—*Automalite, Octahedral Corundum.*—Zn O + Al O^3, part of the Zn being replaced by Mg and Fe, and part of the Al by 2 Fe. **Cubic.** H 7·5 — 8·0

G 4·23 — 4 29. Case 19. *Frac.* conchoidal. *Lus.* vitreous. *Col.* dark leek-green, blackish-green, grayish-green, blue, black. *Str.* gray. Brittle. B. infusible. Not acted upon by acids.

Found embedded in talc slate, in Sweden, Finland, Connecticut.

Chrysoberyl.—*Cymophane, Prismatic Corundum.*—G O + Al O^3. **prismatic.** H 8·5 G 3·680 — 3·754. Case 19. *Frac.* conchoidal. Transparent, semi-transparent. *Lus.* vitreous. *Col.* greenish-white, asparagus-green, oil-green, greenish-gray. *Str.* white. B. infusible. Insoluble in acids.

Found in the Ural, Connecticut, New York, Moravia, Ceylon, Pegu, the Brazils. When transparent and cut with facets, it forms a brilliant yellow gem. When it presents its peculiar milky or opalescent appearance, from which it derives the name of *cymophane*, or floating light, it is cut *en cabochon*. *Chrysoberyl* is distinguished from *moon-stone* and *opalescent quartz* by its superior hardness; from *yellow topaz* by not becoming electric when heated.

Wolframocher.—*Oxide of Tungsten.*—W O^3. **earthy.** Opaque. *Lus.* dull. *Col.* yellow. Soluble in ammonia.

Found at Huntington, in the United States, with wolfram and scheelite.

Coracite.—U^2 O^3. **amorphous.** H 3·0 G 4·378. *Frac.* uneven. *Col.* pitch-black. *Str.* gray. B. infusible. Soluble in hydrochloric acid.

Found on the north shore of Lake Superior.

Plombgomme.—*Hydrous Aluminate of Lead, Plumbo Resinite.*—(PbO + $2AL^2O^3$) + 6HO. **globular masses.** H 5 G 4·88 — 6·421. Case 19. *Frac.* conchoidal. translucent. *Lus.* resinous. *Col.* yellowish, reddish-brown. *Str.* white. B. fusible. Soluble in concentrated nitric acid.

Found in Brittany, Cumberland, and Missouri, in lead mines. Much resembles some varieties of mammilated blende.

Quartz.—*Rhombohedral Quartz, Rock Crystal.*—SiO^2. **rhombohedral.** H 7·0 G 2·5 — 2·8. Cases 21-24. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* white, colourless, violet, blue, rose-red, brown, green. *Str.* white. B. infusible. Insoluble in all acids except *hydro-fluoric acid.*

Amethyst.—This term is now applied to all the violet, purple, blue, white, yellow, and green crystals of quartz which, when fractured, present the peculiar undulated structure described by Sir David Brewster,—it was formerly restricted to the violet specimens. The finest violet amethysts are found in Siberia, India, Ceylon, and Persia; when uniform in tinge, and transparent, they form a gem of great beauty. Crystals of inferior colour to these are found in Transylvania, Hungary, Saxony, the Hartz, and Ireland. White and yellow crystals from the Brazils, when cut, are frequently substituted for the topaz.

Rock Crystal.—This term is used for the transparent crystals found in Switzerland, Savoy, Dauphiné, Piedmont, Quebec, Bristol, Ireland, &c. When pure, it is cut into lenses for spectacles, called *pebbles*; it is also used for vases and other ornamental purposes.

Smoky Quartz.—Applied to the wine-yellow, clove-brown crystals found in Scotland, Bohemia, Pennsylvania, and the Brazils; also called the Scottish *cairngorum*, and much used as an ornamental stone.

Rose or Milk Quartz.—Massive quartz of a rose-red and milk-white colour, found in Bavaria, Finland, and Connecticut.

Prase.—Quartz, coloured of a dark leek-green by admixture of amphibole, found massive in the iron mines of Saxony.

Siderite.—Indigo or berlin-blue quartz. Saltzburg.

Common Quartz comprehends all the massive varieties of quartz not mentioned above; it is found in great abundance, forming veins in primitive and transition rocks, sometimes many hundred feet in thickness.

Hornstone, *Flinty Slate*, *Lydian Stone*, and *Flint*, are names given to the compound varieties of quartz which possess a fine texture.

Float-stone, or *spongiform quartz*, consists of numerous minute white or gray crystals of quartz, which will swim on water, till the air in its numerous cavities is displaced.

Chalcedony is a mixture of crystalline and amorphous quartz, found at Chalcedon, in Asia Minor, Iceland, Faroe Islands, Hungary, Western Islands, Cornwall, India, and Siberia. The red, brown, and yellow varieties are called *carnelians;* the yellow are known to lapidaries as *sarde*, Most oriental cornelians are originally dark gray, and owe their fine red hue to an artificial exposure to heat; found in Arabia, India, Surinam, Saxony, and Scotland.

Agates are composed of irregular layers of chalcedony of various colours.

Mocha-stone and *moss-agates*, are transparent varieties,

The *onyx* is formed of chalcedony, arranged in alternate layers of different colours.

Catseye is chalcedony of a brownish-red or greenish-gray colour, penetrated by amianthus, and exhibiting a play of light; found in Ceylon and Malabar.

Chrysoprase is of an apple-green colour, produced by oxide of nickel; found in Silesia and Vermont.

Avanturine contains many minute fissures or else scales of mica, which reflect bright points of light, and give polished specimens a shining spangle-like appearance; found in Spain and India.

Plasma, a transparent chalcedony of a grass-green or leek-green colour; found in India and China.

Heliotrope, or *blood-stone*, chalcedony coloured by a green earth, and containing spots of yellow or blood-red jasper; found in Bucharia, Tartary, Siberia, and the Hebrides.

Iron-flint, *Eisenkiesel*, or *ferruginous quartz*, contains five per cent. of iron; is found in Saxony, Bohemia, and Hungary.

Jasper is rendered opaque by a mixture of iron and clay. The *striped jasper*, from Siberia, Saxony, and Devonshire, is distinguished by its ribbon-like delineations; the Egyptian jasper, by its red and brown colours and globular structure.

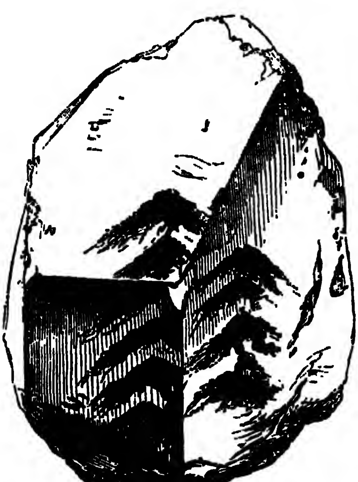


Fig. 395.

Fig. 396.

Fig. 395 is a crystal of quartz in the British Museum, which shows most beautifully the gradual growth of crystals; a transparent hexagonal crystal, terminated by

its planes, similar to Fig. 395 or Fig. 396, was first formed of pure quartz, a deposit of green chlorite then took place on its terminal planes, the crystal was then increased by fresh accessions of silica, still retaining its proper crystalline form, when, after it had considerably increased, another sprinkling of chlorite fell upon its terminal planes; this seems to have been repeated four times. The crystal being very transparent, the chlorite reveals most distinctly four successive stages of its formation. Fig. 396 is a specimen of Egyptian jasper in the British Museum, which is remarkable on account of the natural markings of its fractured surface representing a very tolerable likeness of Chaucer, the poet.

Many agate, onyx, and cornelian cylinders were brought from the ruins of Nineveh, by Mr. Layard.

The moss agates, heliotropes, and flints, from the upper beds of chalk, contain marine organisms, principally sponges.

Opal.—*Resinous Quartz, Uncleavable Quartz.*—**Amorphous.** H 5·5 — 6·5 G 1·9 — 2·3. Case 24. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, yellow, red, brown, green, gray, black. Some varieties exhibit a beautiful play of colours. Very brittle.

Hyalite, or *Muller's glass* appears in small uniform, botryoidal, and sometimes stalactitic shapes, either of a white colour or transparent; found in amygdaloid and in clinkstone. Frankfort, Hungary, and Bohemia.

Fire opal, or *girasol* of the French, possesses bright hyacinth red and yellow tints; found in Mexico and the Faroe Islands.

Noble opal, or *precious opal*, includes all those specimens which exhibit the play of prismatic colours; these are found embedded in porphyry at Czervenitza in Hungary and at Honduras in America, also in Mexico and in Iceland. When large and pure, it is considered a gem of great value.

Common opal and *semi-opal* are devoid of the play of colours, and are distinguished by their different degrees of transparency, lustre, and perfection of their conchoidal fracture; found in porphyry and in the cavities of amygdaloid rocks, Hungary, Faroe, Iceland, Giant's Causeway, and the Hebrides.

Cacholong, nearly opaque, contains a small portion of alumina, and adheres to the tongue; Bucharia, Faroe, Iceland, and Giant's Causeway.

Hydrophane is a variety of opal which is opaque when dry, but transparent when immersed in water; Saxony.

Wood opal is distinguished by its ligneous structure and semi-transparency; found in Hungary, Transylvania, Bohemia, Faroe, and New South Wales.

Siliceous sinter, a deposit from hot springs; the Geyser, in Iceland.

Pearl sinter, or *fiorite*, found in the cavities of volcanic tufa.

Wollastonite.—*Tabular Spar, Prismatic Augite Spar.*—$CaO + Si\,O^2$. **oblique.** H 5·0 G 2·8 — 2·9. Case 25. *Frac.* uneven. Semi-transparent, translucent on the edges. *Lus.* vitreous. *Col.* white, passing into gray, yellow, red, and brown. *Str.* white. Rather brittle. B. fusible with difficulty. Soluble in hydrochloric acid, leaving a jelly of silica.

Found in granular limestone, lava, gneiss, and trap. The Banat, Finland, Sweden, Vesuvius, Canada, United States, Saxony, Ceylon, and Edinburgh. Can be formed artificially by fusing lime and silica.

Okenite.—*Dysclasite.*—$Ca\,O + 2Si\,O^3 + 2HO$. **prismatic.** H 4·5 — 5·0 G 2·28 — 2·36. Case 28. Translucent. *Lus.* pearly. *Col.* yellowish, white, bluish-white. B. fusible. Gelatinizes in hydrochloric acid.

Found in amygdaloid rock. Faroe, Iceland, and Greenland.

Soapstone.—*Steatite.*—$6MgO + 5SiO^3 + 2HO$. **massive.** H 1·5 G 2·266. Case 25. *Frac.* uneven. Translucent on edges. *Lus.* dull. *Col.* yellowish and grayish-white, bluish-gray. *Str.* shining, unctuous. B. fusible. Soluble in sulphuric acid.

Found in serpentine, limestone, &c. Cornwall, Bayreuth, Greenland, St. Helena, China. Used in the manufacture of fine porcelain, for fulling, marking cloth and glass, polishing mirrors and marble, diminishing the friction of machinery, and as a fire-stone for furnaces.

Ottrelite.—*Phyllite.*—$3(1FeO + SiO^2) + (2AlO^3 + 3SiO^2) + 3HO$. Scratches glass. G 4·4. *Frac.* uneven. Translucent. *Lus.* vitreous. *Col.* grayish-black, inclining to green. *Str.* grayish-white. B. fusible. Soluble in hot sulphuric acid.

Found in small hexagonal crystals in clay slate. Ottrez Luxembourg, and Massachusetts.

Meerschaum.—*Earthy Carbonate of Magnesia, Magnesite, Sepiolite, Keffekil.*—$MgO + SiO^3 + HO$? H 2·5 G 1·2 — 1·6. Case 25. *Frac.* earthy. Opaque. *Lus.* dull. *Col.* white, inclining to yellow, red, or gray. *Str.* shining. Adheres to the tongue.

Found in nodules in Greece, Spain, Portugal, Moravia, Sweden, Asia Minor. Used for pipe-bowls. Derives its name, which signifies *froth of the sea*, from its lightness and whitish colour.

Lithomarge.—*Steinmark.*—H 2·5 G 2·496. Case 25. *Frac.* conchoidal. Opaque. *Lus.* dull. *Col.* blue, passing into red and gray. *Str.* shining. Sectile. Adheres to the tongue. B. infusible.

A silicate of alumina and iron, found at Planitz in Saxony.

Serpentine.—*Ophite, Marmolite, Retinalite, Chrysotile, Metaxite, Baltimorite, Picrolite.*—$2(MgO + SiO^2) + (MgO + 2HO)$. H 3·0 G 2·47 – 2·60. Case 25. *Frac.* uneven, conchoidal. Translucent, opaque. *Lus.* resinous, dull. *Col.* green, of various shades. *Str.* white, shining. B. fusible on the edges. Decomposed in powder by hydrochloric and sulphuric acids.

Occurs in masses forming rocks, in beds and veins, and pseudomorphous. Saxony, Bohemia, Moravia, Austria, Styria, Saltzburg, the Tyrol, Hungary, Silesia, Italy, Corsica, Norway, Sweden, Siberia, United States, England, and Scotland. The term *noble* is applied to those serpentines which are of a uniform green colour, and are translucent and fit for cutting. Serpentine is easily cut or turned, and admits of a high polish; it is used for vases, architectural decorations, and other ornamental purposes. It derives the name of *serpentine*, or *ophite*, from its spotted or variegated appearance like the skin of a snake.

Antigorite.—$3(RO + SiO^2) + (MgO + HO)$ where R is Mg and Fe. H 2·5 G 2·62. Case 25. Transparent, translucent. *Lus.* feeble. *Col.* green. *Str.* white. B. fusible on the edges. Decomposed by sulphuric acid.

Found in the valley of Antigorio in Piedmont.

Villarsite.—**Prismatic.** Soft. G 2·978. Case 25. *Frac.* granular. Translucent. *Col.* yellowish-green. B. infusible. Decomposed by strong acids.

Found in a bed of magnetite in Piedmont, supposed to be an altered olivine.

Bronzite.—*Hemiprismatic Schiller Spar, Diallage.* $RO + SiO^2$, where R is Mg and Fe. **oblique.** H 5·0 – 6·0 G 3·2 — 3·6. Case 25. Translucent. *Lus.*

metallic, pearly, frequently resembling bronze. *Col.* dark-green, brown, ash-gray. *Str.* grayish. Slightly brittle. B. fusible with difficulty. Not soluble in acids.

Found in serpentine and basalt. Styria, Bayreuth, Moravia, Cornwall, the Tyrol, Hessia, Silesia, Spain.

Clintonite. — *Xanthophyllit, Chrysophane, Seybertite, Holmesite, Brandisite.* **rhombohedral.** H 4·5 — 6·5 G 3·01 — 3·10. Case 25. *Lus.* vitreous. *Col.* yellow, brown, green. B. infusible. Decomposed by strong hydrochloric acid.

Found in the Ural, Tyrol, and New York.

Olivine.—*Chrysolite, Peridot, Prismatic Chrysolith, Hyalosiderite.*—2 MgO + SiO^2. **prismatic.** H 6·5 — 7·0 G 3·3 — 3·44. Case 25. *Frac.* conchoidal, transparent, translucent. *Lus.* vitreous. *Col.* green, yellow, brown. *Str.* white. Decomposed by sulphuric acid, forming a jelly.

Found in Egypt, Natolia, the Brazils, Styria, Vesuvius, Mexico, Sweden, Baden. The transparent varieties are called chrysolite, the brown hyalosiderite. Chrysolite is prized as a gem when large, free from flaws and of a good colour; it is so soft as to lose its polish unless worn with care. Chrysolite is softer than chrysoberyl, harder and heavier than apatite, and distinguished from the green tourmaline by infusibility and absence of electrical properties when heated. *Chrysolite* is derived from *χρυσος* gold, and *λιθος* stone; and *hyalosiderite* from *ὑαλος* glass, and *σιδηρος* iron.

Picrosmine.—*Prismatic picrosmine steatite.*—2 MgO + SiO^2 + HO. **prismatic.** H 2·5 — 3·0 G 2·59 — 2·66. *Frac.* uneven, opaque. *Lus.* pearly. *Col.* greenish-white, blackish-green. *Str.* white, very sectile. B. infusible.

Found in masses in Bohemia, the Tyrol, and Saxony; distinguished from asbestos by the bitter argillaceous odour it exhales when moistened; hence its name from *πικρὸς* bitter, and *οσμη* smell.

Batrachite.—(2 Ca O + Si O^2) + (2 Mg O + Si O^2). crystalline system undetermined. H 5·0 G 3·033, Case 25. *Frac.* imperfect, conchoidal. Translucent. *Lus.* resinous. *Col.* light greenish-gray, white. *Str.* white. B. fusible.

Found at Rizoni in the Tyrol.

Monticellite.—(2 CaO + Si O^2) + (2 Mg O + Si O^2). **prismatic.** H 5·5 G. 3·245 — 3·275. Case 25. Nearly transparent. *Lus.* vitreous. *Col.* colourless, yellowish. Soluble in hydrochloric acid.

Found in granular limestone at Monte Somma. Named after the Neapolitan mineralogist Monticelli.

Smithsonite.—*Prismatic Zinc Baryte, Prismatic or Electric Calamine, Siliceous Oxide of Zinc, Zinkglas, Galmei.*—2 Zn O + Si O^2 + HO. **prismatic.** H 5·0 G 3·35 — 3·50. Case 26. *Frac.* uneven, transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, yellow, brown, green, blue. *Str.* white. Brittle. Becomes electric when heated. B. infusible. Soluble in acids, leaving a jelly of silica.

Found in veins. Aix-la-Chapelle, Liege, Carinthia, Silesia, Poland, Gallicia, Baden, Derbyshire, Cumberland, Scotland, the Tyrol, Hungary, the Banat, Spain, Siberia, the Hartz. Used as an ore of zinc.

Willemite.—*Siliceous Oxide of Zinc, Brachytype Zinc Baryta, Troostite.*—2 Zn O + Si O^2. **rhombohedral.** H 5·5 G 3·89 — 4·18. Case 26. *Frac.* imperfect conchoidal, semi-transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, yellow,

brown. *Str.* white. Brittle. B. fusible on the edges. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found at Moresnet, Stolberg, Carinthia, Servia, and New Jersey.

Rhodonite.—*Siliciferous Oxide of Manganese, Diatomous Augite Spar.*—Mn O + Si O^2. **oblique.** H 5·0 — 5·5 G 3·61 — 3·65. Case 26. *Frac.* uneven. Translucent. *Lus.* vitreous. *Col.* red, brown, spotted with green. *Str.* reddish-white. B. fusible. Insoluble in hydrochloric acid.

Found in masses. Sweden, Transylvania, the Hartz, New Jersey, Piedmont, Algiers, Cornwall. *Allagite, photizite,* and *corneous manganese,* are all varieties of *Rhodonite.*

Tephroite.—2 Mn O + Si O^2. Crystalline system undetermined. H 5·5 G 4·06 — 4·12. Case 26. *Frac.* uneven. *Lus.* adamantine. *Col.* ash-gray, tarnish brown or black. *Str.* ash-gray. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found with franklinite at Franklin in New Jersey.

Cererite.—*Rhombohedral Cerium Ore, Siliciferous Oxide of Cerium, Cerite, Red Siliceous Oxide of Cerium.*—RO + Si O^2 + 2 HO, where R represents cerium, lanthanium, and didymium. **rhombohedral.** H 5·5 G 4·9 — 5·0. Case 26. *Frac.* uneven, translucent on edges. Opaque. *Col.* brown, red, gray. *Str.* grayish-white. Brittle. B. infusible. Soluble in hydrochloric acid, leaving a jelly of silica.

Found only in an old copper mine at Bastnäs, in Sweden. Resembles red granular corundum, but easily distinguished from it by its inferior hardness.

Tritomite.—**Cubic.** H 5·5 G 4·16 — 4·66. *Frac.* conchoidal. Opaque. *Lus.* vitreous. *Col.* dark-brown. *Str.* yellowish-brown. Very brittle. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found at Lamö in Norway in syenite.

Chlorophæite.—Soft. G 2·02. Case 26. Dull green, and afterwards black. B. infusible. Decomposed by hydrochloric acid.

Found imbedded in amygdaloid rock in the island of Rum, and in Fife.

Chloropal.—*Nontromite, Pinguite.*—Fe^2 O^3 + 2 Si O^3 + 3 HO. Massive. H 3·0 — 4·0 G 2·0. Case 26. *Frac.* conchoidal. Opaque. Translucent on the edges. *Col.* greenish-yellow and pistachio green. *Lus.* vitreous, dull. Brittle. B. infusible.

Found in Hungary and the Hartz.

Stilpnomelane.—**Rhombohedral.** H 3·0 — 4·0 G 3·0 — 3·4. Case 26. Opaque. *Lus.* vitreous. *Col.* black, blackish-green. *Str.* olive-green. Rather brittle. B. fusible. Imperfectly decomposed by acids.

Found in clay slate in Silesia; derives its name from στιλπνος shining and μελας black.

Hisingerite.—*Thraulite, Gillingite, Polyhydrite.*—**Reniform masses.** H 3·0 G 2·79 — 3·05. Case 26. *Frac,* conchoidal. Opaque. *Lus.* resinous. *Col.* black. *Str.* yellowish-brown. Brittle. B. fusible. Partially soluble in hydrochloric acid.

Found in Bavaria and Sweden.

Cronstedtite.—*Sideroschizolite, Rhombohedral Melane Mica.*—2 Fe^2 O^3 + Si O^2 + 2 (2 Fe O + Si O^2) + 5 H O. Reniform and fibrous masses. H 2·5 G 3·348.

Case 26. Translucent. Opaque. *Lus.* vitreous. *Col.* black. *Str.* dark green. Brittle. B. infusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in Bohemia, Cornwall, Brazils, and Chili.

Fayalite.—*Iron Chrysolite.*—2 Fe O + Si O^2. **prismatic.** H 6·5 G 4·11 — 4·14. Case 26. *Frac.* imperfect, conchoidal. Opaque. *Lus.* imperfect, metallic. *Col.* iron-black, inclining to green or brown, brass-yellow tarnish. Magnetic. B. fusible.

Found on the sea-shore at Fayal, and on one of the Morne mountains, Ireland. Crystals having the composition of Fayalite and the form of Olivine, are found in refining cinders and the slag of copper furnaces.

Anthosiderite.—Fe^2 O^3 + 4 Si O^2 + H O. **fibrous.** H 6·5 G 3·0. Case 14. Opaque. *Lus.* silky. *Col.* yellow ochre and brown. *Str.* the same. Very tough. B. fusible. Decomposed by hydrochloric acid.

Found with magnetite in the Brazils; derives its name from *ανθος* a flower and *σιδηρος* iron.

Palagonite.—**Amorphous.** H 3·0 — 4·5 G 2·40 — 2·43. *Frac.* conchoidal. Transparent, translucent. *Lus.* waxy. *Col.* yellow, brown. *Str.* yellow. B. fusible. Decomposable by hydrochloric acid.

Found in volcanic tufa, in Sicily and Iceland.

Chrysocolla.—*Hydrosiliceous Copper, Copper-green, Uncleavable Staphyline Malachite, Kiessel Malachite.*—Cu O + Si O^2 + 2 H O. **amorphous.** H 2·0 — 3·0 G 2·0 — 2·2. Case 26. *Frac.* conchoidal. Semi-transparent. *Lus.* resinous. *Col.* green, sky-blue. *Str.* greenish-white. Slightly brittle. B. infusible. Decomposed by nitric or hydrochloric acid.

Found, with other ores of copper, in the Banat, Hungary, the Tyrol, Bohemia, Saxony, the Ural, Altai, Spain, Norway, New Jersey, Cornwall, Mexico, Chili, Australia.

Dioptase.—*Rhombohedral Emerald Malachite, Emerald Copper Achirite, Kupfer-smaragd.*—CuO + SiO^2 + HO. **rhombohedral.** H 5·0 G 3·27 — 3·348. Case 26. *Frac.* conchoidal, uneven Transparent, translucent. *Lus.* vitreous. *Col.* emerald-green. *Str.* green. Brittle. B. infusible. Soluble in nitric and hydrochloric acids, leaving a jelly of silica.

Found in limestone in the Kirghese Steppes, in Siberia. Derives its name from *δια* through, and *'οπτομαι* to see, in allusion to the possibility of seeing the natural joints by transmitted light. Distinguished from the emerald by inferior hardness, higher specific gravity, and by acquiring negative electricity by friction.

Eulytine.—*Bismuth Blende, Silicate of Bismuth.*—$2BiO^3$ + $3SiO^3$. **cubic.** H 4·5 — 5·0 G 5·965. Case 26. *Frac.* uneven. Semi-transparent. Opaque. *Lus.* adamantine. *Col.* brown or yellow. *Str.* yellowish-gray. Brittle. B. fusible. Soluble in hydrochloric acid, leaving a jelly of silica.

Found in minute crystals in cobalt veins. Schneeberg and Braünsdorf in Saxony.

Zircon.—*Pyramidal Zircon, Hyacinth.*—ZrO + SO^2. **pyramidal.** H 7·5 G 4·0 — 4·7. Case 26. *Frac.* conchoidal, uneven. Transparent, translucent on the edges. *Lus.* vitreous. *Col.* red-brown, yellow, gray, green, white. *Str.* white. B. infusible. Partially decomposed by sulphuric acid.

The term *hyacinth* is applied to transparent and bright-coloured varieties, *Jargoon* to crystals devoid of colour and of a smoky tinge, occasionally sold as inferior diamonds.

Zirkonite to the gray and brown, rough and opaque varieties. Found in gneiss, granite, volcanic matter, alluvium, and sand of rivers. Ceylon, Norway, Siberia, New Jersey, Sweden, Greenland, Egypt, Carinthia, France, Italy, Vesuvius, the East Indies, Saxony, the Ural, Transylvania.

Ostranite is a grayish-brown zircon from Fredricksvärn.

Malacone and *Oerstedtite*, names given to two minerals having the form of zircon, and supposed to be that mineral in a stage of decomposition.

Thorite.—$2ThO + SiO^2 + 2HO$. **massive.** H 4·5 G 4·63. Case 26. *Frac.* conchoidal. *Lus.* vitreous. *Col.* black. *Str.* dark-brown. Brittle. B. infusible. Gelatinizes in hydrochloric acid.

Found with mesotype, at Lövö in Norway. It was from this mineral Berzelius first obtained the rare metal *thorium*.

Andalusite.—*Prismatic Andalusite.*—$AlO^3 + SiO^2$. **prismatic.** H 7·5 G 3·1—3·2. Case 26. *Frac.* uneven, flat, conchoidal. Transparent, translucent on the edges. *Lus.* vitreous. *Col.* reddish, passing into pale gray. *Str.* white. B. infusible. Slightly affected by acids.

Found in granite, gneiss, and mica slate. Spain, the Tyrol, Bavaria, Bohemia, Moravia, Silesia, Saxony, France, Siberia, Brazils, Banffshire, Ireland, Connecticut, Massachusetts. Distinguished from *felspar* by its hardness and infusibility, from *corundum* by its structure and specific gravity.

Chiastolite, or *hollow spar*, appears to be a variety of *andalusite*, having prisms of a darker substance in the centre and sometimes in each angle, connected by thin plates of the same. H 5·0 — 5·5 G 2·9 — 2·95. Derives its name from the summits of its crystals being marked in the form of the Greek letter X. Found in the Pyrenees, Spain, Normandy, Cumberland, Wicklow.

Kyanite.—*Disthéne, Sillimanite. Bucholzite, Fibrolite, Prismatic Disthene Spar, Monrolite, Rhætizit.*—$AlO^3 + SiO^2$. **anorthic.** H 5·0 — 6·0 G 3·58 — 3·62. Case 26. *Frac.* uneven. Transparent, translucent. *Lus.* pearly, vitreous. *Col.* blue, white, gray, black, colourless. *Str.* white. Brittle. B. infusible. Insoluble in acids.

Found in mica slate, granite, gneiss, &c. Switzerland, Styria, Carinthia, Banffshire, United States, Bohemia, South America, Massachusetts, the Tyrol, Shetland. Distinguished from *actinolite* by its infusibility, cleavage, and specific gravity. When blue and transparent, is cut and polished as an ornamental stone, resembling *sapphire*.

Bamlite.—H 6·5 — G 2·984. *Frac.* uneven. Translucent. *Lus.* vitreous. *Col.* white, inclining to green.

Found in slender prisms and crystalline masses, with quartz, in Norway.

Worthite.—$4\ AlO^3 + 5\ SiO^2 + 2\ HO$. Granular aggregations. H 7·0 — 7·5 G 3·0. Case 26. Feebly translucent. *Lus.* pearly. *Col.* white. B. infusible. Insoluble in acids.

Found in the neighbourhood of St. Petersburg.

Allophane.—*Riemanite.*—$3\ Al^2\ O^3 + 2\ Si\ O^3 + 15\ H\ O$. Reniform and botryoidal masses. H 3·0 G 1·852 — 1·889. Case 26. *Frac.* flat, conchoidal, semitransparent. Translucent on the edges. *Lus.* waxy. *Col.* white, yellow, red, brown, blue and green. Brittle. B. infusible. Gelatinizes with acids.

Found in Saxony, Moravia, and Bohemia. Derives its name from ἄλλος and φαίνω to appear, from its change of appearance under the blowpipe.

Halloysite.—*Lenzinite, Smectite.*—A hydrous silicate of alumina. H 1·5 — 2·5

G 1·92 — 2·12. Case 26. *Frac.* conchoidal. Opaque. *Lus.* waxy. *Col.* white, blue, green, yellow. B. infusible. Gelatinizes with sulphuric acid.

Found in reniform masses. Silesia, France, New Granada.

Collyrite.—*Scarbroite.*—A hydrous silicate of alumina. H 1·0 — 2·0 G 2·06 — 2·11. Case 26. *Frac.* earthy. Opaque. *Lus.* dull. *Col.* white, reddish, greenish. *Str.* shining. Unctuous to the touch. B. infusible.

Found in reniform masses in the Pyrenees.

Bole.—A silicate of alumina and iron. H 1·5 — 2·5 G 1·6 — 2·0. Case 26. *Frac.* conchoidal. Opaque. *Col.* brown. *Str.* resinous. Sectile.

Found in nodules. Silesia, Bohemia, Saxony, Hebrides.

Schrotterite.—4 $Al^2 O^3 + Si O^3 + 3 H O$. Amorphous. H 3·0 — 3·5 G 1·985 — 2·015. Case 26. *Frac.* conchoidal. Translucent. *Lus.* vitreous. *Col.* light emerald green. *Str.* white. Brittle. B. infusible. Gelatinizes with hydrochloric acid.

Found in nodules in Styria.

Miloschine.—*Serbian.*—$Al O^3 + Si O^2 + 3 H O$. Massive. H 1·5 — 2·0 G 2·131. *Frac.* conchoidal. *Lus.* glimmering dull. *Col.* blue-green. B. infusible. Partially decomposed by hydrochloric acid.

Found massive in Servia.

Groppite.—Crystalline masses. H 2·5 G 2·73. *Frac.* splintering. Semi-transparent in thin fragments. *Col.* Rose-red, brown, red. *Str.* light. Brittle. B. fusible on the edges.

Dillnite.— H 3·5 G 2·835. *Frac.* conchoidal. Opaque. *Lus.* dull. *Col.* white. Case 26.

Found in veins of limestone at Schemnitz in Hungary.

Agalmatolite.—*Figure stone, Talcglaphique, Bildstein.*—H 3·0 G 2·75 — 2·85. Case 26. *Frac.* uneven. *Col.* white, pale gray, green, yellow, flesh red. *Str.* white and shining. Slightly brittle, almost sectile. B. fusible on the thinnest edges. Decomposed by hot sulphuric acid.

Found in China, Saxony and Hungary. Carved by the Chinese into grotesque figures and ornaments.

Apophyllite.—*Pyramidal Kouphone Spar, Oxhaverite, Pyramidal Zeolite, Ichthyopthalmite, Tessalite, Alvine.*—3 (Ca O, K O, H O) + 2 $Si O^3 + 2 H O$. **pyramidal.** H 4·5 — 5·0 G 2·35 — 2·39. Case 27. *Frac.* imperfect, conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, yellow, blue, red, green. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid.

Found in cavities of amygdaloid rocks, in veins in transition slate, and in beds of magnetite. The Banat, the Tyrol, Iceland, the Hartz, Hindostan, Bohemia, Sweden, Greenland, Siberia, North America, Fifeshire. *Apophyllite* derives its name from *απο* and *φυλλον* a leaf, on account of its tendency to exfoliate under the blowpipe. The peculiar pearly lustre of the crystallized varieties, which is one of the most decided characteristics of this mineral, gave rise to the name *ichthyopthalmite*, or fish eye-stone, from *ιχθυς* a fish and *οφθαλμος* an eye.

Chabasie.—*Rhombohedral Kouphone Spar, Phacolite, Rhombohedral Zeolite.*—$(Ca O + Si O^2) + (Al O^3 + 3 Si O^2) + 6 H O$. **rhombohedral.** H 4·0 — 4·5 G 2·08 — 2·15. Case 27. *Frac.* uneven. Semi-transparent, semi-translucent. *Col.* colourless,

white, reddish, yellowish. *Str.* white. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in cavities and veins in amygdaloid and plutonic rocks. Bohemia, the Tyrol, Faroe, Iceland, Greenland, Sweden, Ireland, Renfrewshire, Hungary, Siberia, Massachusetts.

Mesotype.—*Zeolith, Natrolith, Bergmannite, Mesolite, Radiolite, Peritomous Kouphone Spar.*—($Na\,O + Si\,O^2$) + ($Al\,O^3 + 2\,Si\,O^2$) + $H\,O$. **prismatic.** H 5·0 – 5·5 G 2·24 – 2·26. Case 27. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, gray, yellow, red, pale green. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in basalt, syenite, and transition rocks. Greenland, Iceland, Bohemia, the Tyrol, Ireland, Norway.

Scolezite.—*Needlestone, Poonahlite, Antrimolite.*—($Ca\,O + Si\,O^2$) + ($Al\,O^3 + 2\,Si\,O^2$) + $3\,H\,O$. **oblique.** H 5·0 — 5·5 G 2.2 — 2·3. Case 28. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, reddish, yellowish. Brittle. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in cavities of amygdaloid rocks. Staffa, Faroe, Iceland, Greenland, Hindostan, the Tyrol, Ireland. Curls up before the blowpipe, whence its name from σκωληξ a worm.

Comptonite.—*Thomsonite, Orthotomous Kouphone Spar.*—3 ($Al\,O^3 + Si\,O^2$) + 3 ($Ca\,O + Si\,O^2$) + $7\,H\,O$. **prismatic.** H 5·0 — 5·5 G 2·31 — 2·38. Case 27: *Frac.* imperfect, conchoidal. Transparent, translucent. *Col.* white, yellow, red. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in amygdaloid rocks. Vesuvius, Hessia, Bohemia, Greenland, Iceland, the Tyrol, Scotland.

Gmelinite.—*Hydrolite, Sarcolite, Heteromorphous Kouphone Spar, Herschelite.*—($R\,O + Si\,O^2$) + ($Al\,O + 3\,Si\,O^2$) + $6\,H\,O$, where R is K, Ca, and Na. **rhombohedral.** H 4·5 G 2·04 – 2·12. Case 27. *Frac.* uneven. Translucent. *Lus.* vitreous. *Col.* white, reddish. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in cavities of amygdaloid rocks. Vicentine, Ireland, Sicily.

Levyne.—*Macrotypous Kouphone Spar.*—($Ca\,O + Si\,O^2$) + ($Al\,O^3 + 3\,Si\,O^2$) + $6\,H\,O$. **rhombohedral.** H 4·0 G 2·1 — 2·2. Case 27. *Frac.* imperfect, conchoidal. Semi-transparent. *Lus.* vitreous. *Col.* white, grayish. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in cavities in trap. Ireland, Renfrewshire, Faroe, Iceland, Skye.

Gyrolite.—*Gurolite.* $2\,Ca\,O + 3\,Si\,O^2 + 3\,HO$. H 3·0 – 4·0. Case 28. *Lus.* vitreous, thin plates, transparent. *Col.* white. Very tough. B. fusible.

Occurs in small spherical concretions in the cavities of basalt, from Storr in Skye.

Edingtonite.—*Pyramidal Brythine Spar, Hemi-pyramidal Spar.* **Pyramidal.** H 4·0 – 4·5 G 2·71. Case 28. *Frac.* imperfect, conchoidal. Semi-transparent, translucent. *Col.* grayish-white. *Str.* white. Brittle. B. fusible. Forms a jelly in hydrochloric acid without being completely decomposed.

Found in small crystals in amygdaloid. Dumbarton, Scotland.

Algerite.—Oblique. H 3·0 — 3·5 G 2·697 — 2·948. Translucent. Opaque. *Lus.* vitreous. *Col.* yellowish-white. *Str.* light-brown. B. fusible. Slightly acted on by hydrochloric acid.

Found in white limestone. Franklin, New Jersey.

Analcime,—*Hexahedral Kouphone Spar.*—($Na\,O + Si\,O^2$) + ($Al\,O^3 + 3\,Si\,O^2$) + 2 HO. **cubic.** H 5·5 G 2·22 — 2·28. Case 28. *Frac.* uneven, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, reddish-white. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in cavities of amygdaloid rocks, in beds of magnetite, gneiss, porphyry. The Tyrol, Scotland, Ireland, Bohemia, the Ural, Faröe, Iceland, Norway, the Hartz.

Eudnophite.—($Na\,O + Si\,O^2$) + ($Al\,O^3 + 3\,Si\,O^2$) + HO. **prismatic.** H 5·5 G 2·27. *Frac.* even. Transparent. *Lus.* pearly. *Col.* white, gray, brown. *Str.* white. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in syenite. Lamö, near Brevig.

Stilbite.—*Desmin Prismatoidal Kouphone Spar.*—($Ca\ O + 3\ Si\ O^2$) + ($Al\ O^3 + 3\ Si\ O^2$) + 6 HO. **prismatic.** H 3·5 – 4·0 G 2·1 – 2·2. Case 28. *Frac.* uneven. Semi-transparent. *Lus.* vitreous. *Col.* colourless, white, yellow, red, brown. *Str.* white. Brittle. B. fusible. Decomposed by acids.

Found in cavities of amygdaloidal rocks, also in beds and veins in granite and slate. Iceland, Faröe, Skye, Hindostan, the Tyrol, Norway, Sweden, Silesia, the Hartz, the Alps, Scotland, Siberia.

Epistilbite.—*Diplogenous Kouphone Spar.*—($Ca\ O + 3\ Si\ O^2$) + ($Al\ O^3 + 3\ Si\ O^2$) + 5 HO. **prismatic.** H 3·5 – 4·0 G 2·24 – 2·25. Case 28. *Frac.* uneven, transparent. *Lus.* vitreous. *Col.* colourless, white. *Str.* white. B. fusible. Decomposed by strong hydrochloric acid.

Found in cavities of amygdaloidal rocks. Iceland, Faröe.

Heulandite.—*Hemiprismatic Kouphone Spar.*—($Ca\ O + 3\ Si\ O^2$) + ($Al\ O^3 + 3\ Si\ O^2$) + 5 HO. **oblique.** H 3·5 – 4·0 G 2·18 – 2·22. Case 28. *Frac.* uneven, transparent. *Lus.* vitreous. *Col.* colourless, white, gray, brown, red. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid.

Found in cavities of amygdaloidal rocks. Iceland, Faröe, Hindostan, Nova Scotia, Bohemia, the Tyrol, Transylvania, Norway, the Hartz, Saxony, Siberia, Scotland, Skye.

Brewsterite. — *Megalagonous Kouphone Spar.* — **Oblique.** H 5·0 — 5·5 G 2·12 — 2·20. Case 28. *Frac.* uneven. Brittle. B. fusible with difficulty. Decomposed by hydrochloric acid.

Found in cavities of amygdaloidal rocks. Scotland, Ireland, France, and the Pyrenees.

Laumonite. — *Leonhardite, Diatomous Kouphone Spar, Di-prismatic Zeolite.*— ($CaO + SiO^2$) + ($AlO^3 + 3SiO^2$) + 4HO. **oblique.** H 3·5 G 2·33 — 2·41. Case 28. *Frac.* uneven. Translucent. *Lus.* vitreous. *Col.* yellowish and grayish-white, flesh-red. *Str.* white. Very brittle. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in cavities of amygdaloid, and in metallic veins. Bretagne, Bohemia, the Tyrol, Hungary, Sweden, the Ural, North America, Faröe, Iceland, Skye, Ireland, Scotland. Specimens of this mineral ought to be covered with a thin solution of gum arabic, to counteract the rapid decomposition which takes place when they are exposed to the air.

Prehnite.—*Axotomous Triphane Spar, Koupholite, Edelith, Chiltonite.*—2($CaO + SiO^2$) + ($AlO^3 + SiO^2$) + HO. **prismatic.** H 6·0 – 7·0 G 2·92 – 3·01. Case 29. *Frac.* uneven. Semitransparent, translucent. *Lus.* vitreous. *Col.* green, yellow, gray. *Str.* white. Brittle. Becomes electric by the application of heat. B. fusible. Partially soluble in hydrochloric acid.

Found in granite and crystalline rocks. Dauphiné, the Tyrol, Pyrenees, Switzerland, Saxony, the Hartz, Norway, Sweden, Massachusetts, South Africa, Scotland, Gloucestershire, Staffordshire, Land's End, China. The grass-green varieties have been mistaken for chrysolite, chrysoprase, and emerald.

Nephrite.—*Jade, Uncleavable Nephrite Spar, Beilstein.*—($CaO + SiO^3$) + ($3MgO + 2SiO^3$). H 5·5 — 6·0 G 2·65 – 3·0. Case 29. *Frac.* splintery. Translucent on the edges. *Lus.* resinous, dark. *Col.* leek-green, greenish-white, greenish-gray. *Str.* white, shining. Tough. Slightly unctuous to the touch. B. fusible on the edges.

Found massive and in blocks with slate and limestone. India, Turkey, Leipsig, Little Thibet, China, Egypt, the Amazon. Vessels made from Jade are as sonorous as porcelain. It is wrought into hatchets by the New Zealanders. Derives its name from *νεφρος a kidney*, because it was supposed to be a remedy for diseases of that organ.

Harmotome.—*Paratomous Kouphone Spar, Staurolite, Pyramidal Zeolite or Cross stone, Morvenite, Andreolite, Andreasbergolite.*—($BaO + 2SiO^2$) + ($AlO^3 + 3SiO^2$) + $5HO$. **prismatic.** H 4·5 G 2·39 — 2·50. Case 29. *Frac.* uneven, imperfect conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* white, colourless, gray, yellow, brown, red. *Str.* white. Brittle. B. fusible. In powder decomposed by hydrochloric acid.

Found in metallic veins, and in cavities of amygdaloidal rocks and basalt. Scotland, the Hartz, Norway, Silesia, Oberstein. Derives its name from *αρμος a joint*, and *τεμνω to cut*, from the appearance of its twin crystals.

Phillipsite.—*Gismondine, Zeagonite, Lime Harmotome, Christianite, Abrazite, Staurotypous Kouphone Spar.*—($RO + SiO^2$) + ($AlO^3 + 3SiO^2$) + $5HO$. **prismatic.** H 4·5 G 2·14 – 2·213. Case 29. *Frac.* conchoidal, uneven. Translucent, translucent on the edges. *Lus.* vitreous. *Col.* white, gray, colourless, blue, yellow, red. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in cavities of amygdaloid and basalt. Bohemia, Silesia, Bonn, Oberstein, Vesuvius, Sicily, Rome, Giant's Causeway. Resembles *Harmotome*, but distinguished from it by its lower specific gravity.

Felspar.—*Orthoclase, Orthotomous Felspar, Adularia, Murchisonite, Sanidine, Mikroklin, Amazon stone, Perthite.*—($KO + 3SiO^2$) + ($AlO^3 + 3SiO^2$). **oblique.** H 6·0 G 2·53 — 2·59. Case 29. *Frac.* conchoidal, uneven. Transparent, translucent on the edges. *Lus.* vitreous. *Col.* colourless, white, gray, green, brown, red, flesh-red, verdigris-green. *Str.* grayish-white. Brittle. B. fusible with difficulty. Not acted on by acids.

Adularia, or transparent Felspar, is found in plutonic and metamorphic rocks. St. Gotthardt, Mont Blanc, Dauphiné, Norway, Arran, Cornwall, Snowdon, Ceylon, Greenland.

Moon Stone, a transparent colourless felspar, from Ceylon, which presents a play of light; used as an ornamental stone.

Common Felspar. Italy, Silesia, Ireland, the Ural, Bohemia, Brazils.

Green Felspar (Amazon Stone), found on the east side of Lake Ilmen.

Glassy Felspar (Sanidine), found in trachyte, basaltic, conglomerate, and volcanic

masses. The Rhine, Mexico, Chili, Baden, Hungary, Italy, Iceland, Cassel, Vesuvius, Arran.

Murchisonite is a flesh-red variety of felspar, found in rolled pebbles. Heavitree, Exeter.

Crystals of flesh-red felspar have been found in a copper furnace, and of adularia in an iron furnace.

The porcelain earth, or *Kaolin* of the Chinese, is produced by the decomposition of felspar. Felspar is extensively used in the manufacture of porcelain.

Pollux.—A hydrosilicate of alumina and potash. H 6·0 — 6·5 G 2·868 — 2·892. Case 29. *Frac.* conchoidal. Transparent. *Lus.* vitreous. *Col.* white, colourless. B. fusible on the edges. Decomposed by acids.

Found with petalite in cavities of granite at Elba.

Labradorite.—*Labrador Felspar, Anhydrous Scolecite, Manilite, Silicite, Opaline Felspar, Polychromatic Felspar.*—(R O + Si O^2) + (Al O^3 + 2 Si O^2) where R is Ca or Na. **anorthic.** H 6·0 G 2·67 — 2·76. Case 30. *Frac.* imperfect conchoidal. Faintly translucent. *Lus.* vitreous. *Col.* gray, red, green, white, blue. B. fusible. Decomposed by concentrated hydrochloric acid when in powder.

Occurs principally as a constituent of rocks. The varieties which exhibit a play of colours are mostly derived from a coarse-grained hypersthene rock. Labrador, Russia, Finland, Ireland, the Tyrol, the Hartz, Scotland, Corsica, Saxony, Hessia, Sweden, Faröe, Norway, Ætna, Vesuvius. The play of colours is supposed to be produced by microscopic crystals of quartz included in the labradorite. It receives a good polish, and is valued for ornamental purposes on account of its beautiful colours.

Pectolite.—*Stellite, Osmelite, Woolastonite.*—4 R O + 3 Si O^2 + H O where R is Ca and Na. H 4·0 — 5·0 G 2·745 — 2·756. Case 29. Translucent on the edges. *Lus.* pearly. *Col.* grayish-white. Brittle. B. fusible. Decomposed by hydrochloric acid.

Found in spherical masses, in amygdaloid and felspar. Verona, the Tyrol, Lake Superior, New Jersey, Scotland, Bavaria.

Faujasite.—(R O + Si O^2) + (Al^2 O^3 + 2 Si O^2) + 9 H O where R is Na and Ca. **pyramidal.** H 5·0 G 1·923. Case 29. *Frac.* uneven. Transparent, translucent on the edges. *Lus.* vitreous. *Col.* white, brown, colourless. Brittle. B. fusible. Decomposed by hydrochloric acid.

Found in cavities of amygdaloidal rock. Sassbach.

Latrobite. — *Diploite.*—A hydrosilicate of alumina. **anorthic.** H 5·0 — 6·0 G 2·720 — 2·722. Case 29. *Frac.* uneven. Translucent. *Lus.* vitreous. *Col.* pale red. B. fusible.

Found with felspar, mica and calcite. Labrador and Massachusetts.

Albite. — *Pericline, Cleavelandite, Heterotomous Felspar, Tetartine, Tetarto-prismatic Felspar.*—(NaO + $3SiO^2$) + (AlO^3 + $3SiO^2$). **anorthic.** H 6·0 — 6·5 G 2·54 — 2·64. Case 30. *Frac.* imperfect conchoidal. Transparent, translucent on the edges. *Lus.* vitreous. *Col.* colourless, white, red, yellow, green, gray. *Str.* white. Brittle. B. fusible. Not decomposed by acids.

Found in granite, gneiss, greenstone, and lava. Dauphiné, the Pyrenees, Italy, Saxony, Silesia, the Hartz, the Tyrol, Moravia, Baden, Greenland, Siberia, the Alps, Sweden, Scotland, Ireland, Cornwall, Egypt, the Brazils, Massachusetts. Derives its name from *albus*, white.

Christianite.—*Anorthite, Amphodelite, Indianite, Lepolite, Anorthotomous Felspar.*—$(CaO + SiO^2) + (AlO^3 + SiO^2)$. **anorthic.** H 6·0 G 2·656 — 2·763. Case 30. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid.

Found in dolomite, in lava, and in meteoric stones. Vesuvius, Java, Iceland, Columbia. Distinguished from topaz by inferior hardness and specific gravity.

Oligoclase.—*Antitomous Felspar, Soda Spodumene, Unionite.*—$(2NaO + 3SiO^2) + 2)AlO^3 + 3SiO^2)$. **anorthic.** H 6·0 G 2·63 – 2·74. Case 30. *Frac.* conchoidal, uneven. Translucent. *Lus.* vitreous. *Col.* greenish white and gray, red. *Str.* white. B. fusible. Not acted on by acids.

Found in granite, syenite, gneiss, porphyry, and basalt. Norway, Finland, the Ural, United States, the Hartz, Iceland. The oligoclase from Norway, which presents a play of colours produced by thin plates of hematite, is called *aventurine felspar* and *sunstone.* Derives its name from ολιγος *little*, and κλαω *to cleave.*

Porzellanspath.—$(3AlO^3 + SiO^2) + 3(CaO + SiO^2) + (NaO + 3SiO^2)$. **prismatic.** H 5·5 G 2·65 — 2·68. *Frac.* uneven. Translucent on the edges. *Lus.* vitreous. *Col.* yellowish and grayish-white. Brittle. B. fusible. Decomposed by concentrated hydrochloric acid.

Found in felspar and granite. Obernzell, near Passau. Decomposed by exposure to the air.

Leucite.—*Amphigene, Dodecahedral Zeolite, Trapezoidal Amphigene Spar.*—$(KO + SiO^2) + (AlO^3 + 3SiO^2)$. **cubic.** H 5·5 — 6·0 G 2·45 – 2·50. Case 31. *Frac.* conchoidal, uneven. Semi-transparent, translucent. *Lus.* vitreous. *Col.* grayish, yellowish, and reddish-white. Brittle. B. infusible. In powder decomposed by hydrochloric acid.

Found in lava, trachyte, and dolerite. Italy and the Rhine. Millstones formed of lava in which leucite was imbedded, have been found at Pompeii. It derives its name from λευκος, *white*, It has been called the white garnet.

Spodumene.—*Triphane, Prismatic Triphane Spar.*—A silicate of alumina.—**Oblique.** H 6·5 — 7·0 G 3·07 — 3·20. Case 31. *Frac.* uneven, splintery. Translucent on the edges. *Lus.* vitreous. *Col.* greenish-white and gray. *Str.* white. B. fusible. Not acted on by acids.

Found in gneiss and granite. Utö, the Tyrol, Ireland, Scotland, Massachusetts. Named from σποδος *ashes*, because it becomes ashy before the blowpipe.

Petalite.—*Prismatic Petaline Spar, Castor.*—A silicate of alumina. H 6·0 — 6·5 G 2·38 — 2·43. Case 31. *Frac.* imperfect, conchoidal. Translucent. *Lus.* vitreous. *Col.* white, green, red. *Str.* white. Brittle. B. fusible. Not decomposed by acids.

Found in masses and in granite. Utö, Massachusetts, Ontario, Elba. It was in the analysis of this mineral that *lithia* was first discovered.

Davyne.—*Davytic Kouphone Spar, Cancrinite, Cavolinite.*—A silicate of alumina, soda, and lime. **Rhombohedral.** H 5·5 G 2·42 — 2·46. Case 31. *Frac.* conchoidal. Translucent. *Lus.* vitreous. *Col.* colourless, white, rose-red. B. fusible. Soluble in hydrochloric acid, leaving a jelly of silica.

Found in lava and miascite. Vesuvius, Maine, the Ural. Named in honour of Sir Humphrey Davy.

Nepheline.—*Rhombohedral Felspar, Rhombohedral Elain Spar, Elæolite, Sommite.*—(4 R O + 3 Si O^2) + 2 (2 Al O^3 + 3 Si O^2), where R is Na, K, and Ca. **Rhombohedral.** H 5·5 — 6·0 G 2·58 — 2·64. Case 31. *Frac.* conchoidal, uneven. Transparent, feebly translucent. *Lus.* vitreous. *Col.* colourless, greenish-gray, bluish-green, flesh-red. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in basalt, dolerite, and syenite. Vesuvius, Rome, Heidelberg, Hessia, Saxony, Norway, the Ural. Derives its name from νεφελη *a cloud*, from the nebulous appearance assumed when fragments are thrown into nitric acid.

Scapolite.—*Meionite, Dypyre, Wernerite, Terenite, Paranthine Elain Spar, Glaucolite, Ekebergite, Tetraklasit, Nuttallite. Stroganowite.*—(3 Ca O + 2 Si O^2) + 2 (Al O^3 + Si O^2). **pyramidal.** H 5·0 — 5·5 G 2·61 — 2·78. Case 31. *Frac.* conchoidal. Translucent, opaque. *Lus.* vitreous. *Col.* colourless, white, gray, green, red. *Str.* white. Brittle. B. fusible. Decomposed when in powder by hydrochloric acid.

Found in limestone and in iron mines. Vesuvius, Norway, Sweden, Finland, Moravia, Greenland, France, and North America. The name *meionite* is applied to the transparent varieties.

Dipyre.—*Schmelzstein.*—4 (RO + Si O^2) + 3 (Al^2O^3 + Si O^2). G 2·646. Scratches glass. Case 31. Transparent, translucent. *Col.* whitish or reddish. B. fusible.

Found in hexagonal prisms with talc or chlorite in the Pyrenees.

Rhyacolite.—*Empyrodoxous Felspar.*—(RO + Si O^2) + (Al O^3 + 2 Si O^2), where R is Na. K, and Ca. **oblique.** H 6·0 G 2·57 — 2·62. *Frac.* conchoidal, transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, grayish, yellowish, *Str.* white. Very brittle. B. fusible. Decomposed by hydrochloric acid.

Found in lava and volcanic matter. Vesuvius, Eiffel, Laach. Derives its name from ρυαξ, a *lava stream.*

Latrobite.—*Diploite.*—A silicate of alumina. **anorthic.** H 5·0 — 6·0 G 2·720 — 2·722. Case 31. *Frac.* uneven, translucent. *Lus.* vitreous. *Col.* pale red.

Found with felspar, mica, and calcite. Amitok, near Labrador.

Ittnerite.—*Dodecahedral Amphigene Spar, Haüyn.*—A hydrosilicate of alumina, soda, and lime. **cubic.** H 5·5 G 2·373 — 2·377. Case 31. *Frac.* flat conchoidal, translucent on the edges. *Lus.* resinous. *Col.* dark bluish-gray, smoke-gray, ash-gray. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in basalt. The Eichberg Baden.

Sarcolite. — *Octahedral Kouphone Spar.* — A silicate of lime and alumina. **pyramidal.** H 6·0 G 2·545. *Frac.* conchoidal, semi-transparent, translucent. *Lus.* vitreous. *Col.* flesh-red, white. Very brittle. B. fusible.

A rare mineral, found at Vesuvius.

Mica.—*Oblique Mica, Biaxial Mica, Potash Mica, Hemiprismatic Talk Glimmer, Muscovite.*—A silicate of alumina. **oblique.** H 2·5 G 2·8 — 3·1. Case 32. *Frac.* conchoidal. Transparent. *Col.* colourless, white, various shades of gray, brown, green, black. *Str.* white, gray. Sectile. B. fusible. Not decomposed by acids.

An essential constituent of granite, gneiss, and mica slate; found also in veins and cavities in porphyry, basalt, dolomite, limestone and lava. Vesuvius, Siberia, Finland, Green-

land, United States, Norway. Occasionally found in the slags of furnaces. In Siberia thin sheets of mica are used for glazing windows, whence it has been called *Muscovy glass*. It is divisible into plates the $\frac{1}{150000}$th part of an inch in thickness.

Biotite.—*Hexagonal Mica, Uniaxial Mica, Magnesia Mica, Rubellan, Rhombohedral Talk Glimmer, Meroxen.*—($3\ R\ O + 2\ Si\ O^2$) + ($Al\ O^3 + Si\ O^2$) where R is Mg, K, and Fe. **rhombohedral.** H 2·0 — 2·5 G 2·78 — 2·95. Case 32. Transparent, translucent. *Lus.* metallic. *Col.* dark green, brown, verging into black. *Str.* white, pale greenish gray. Sectile. Thin leaves. Elastic. B. fusible with difficulty. Decomposed by sulphuric acid.

Found in granite and chlorite slate. The Ural, New Jersey, Greenland, Vesuvius, Siberia.

Lepidolite.—*Lithia Mica, Lithonite, Hemiprismatic Talk Glimmer.*—A silicate of alumina. **oblique.** H 2·0 — 3·0. G 2·8 — 3·0. Case 32. *Frac.* conchoidal. Transparent, translucent on the edges. *Lus.* pearly, inclining to adamantine, vitreous. *Col.* white, green, gray, red, violet. *Str.* white. In thin leaves, elastic. B. fusible. Acted on by acids.

Occurs principally in granite. Moravia, Saxony, the Ural, Maine, Connecticut, Bohemia. Saxony and Cornwall.

Wichtisite.—A silicate of alumina and iron. G 3·03. *Frac.* imperfect, conchoidal. *Lus.* dull. *Col.* black. Magnetic.

Found at Wichtis, in Finland.

Glaucophane.—A silicate of alumina and iron. H 5·5 G 3·103 — 3·113. *Frac.* conchoidal. Translucent, nearly opaque. *Lus.* vitreous. *Col.* bluish-gray. *Str.* the same. Magnetic in powder. B. fusible. Imperfectly decomposed by acids.

Found in mica slate in the Island of Syra. Derives its name from γλαυκος *bluish-gray*, and φαινω *to appear*.

Margarite.—*Hemiprismatic Perl Glimmer, Emerylite, Corundellite, Clingmanite.*—A silicate of alumina. **oblique.** H 3·5 — 4·5 G 3·0 — 3·1. *Frac.* conchoidal. Semi-transparent, translucent. *Lus.* pearly, vitreous. *Col.* reddish- and greenish-white, pearl gray. *Str.* white. Rather brittle. B. fusible. Acted on by acids.

Found in the Tyrol with chlorite. United States, Asia Minor, the Ural.

Lepidomelane.—($R^2\ O^3 + Si\ O^2$) + ($R^1 + Si\ O^2$). H 3·0 G 3·0. Opaque. *Lus.* vitreous. *Col.* black. *Str.* green. Rather brittle. B. fusible. Easily decomposed by hydrochloric acid.

Found at Persberg, in Sweden. Derives its name from its colour and structure, λεπις *a scale*, and μελας *black*.

Talc.—*Prismatic Talk Glimmer, Potstone, Soapstone, Steatite.*—$6\ Mg\ O + 5\ Si\ O^2 + 2\ HO$. **prismatic?** H 1·0 — 1·5 G 2·6 — 2·8. Case 32. *Frac.* splintery. *Lus.* pearly, more or less translucent. *Col.* blue, green-gray by transmitted, and silver-white by reflected, light. *Str.* white. Thin leaves flexible but not elastic, unctuous to the touch. B. fusible with great difficulty. Not acted on by acids.

Occurs alone as talk-slate, and is a constituent of some granular rocks. The Tyrol, St. Gotthard. Sweden, Bavaria, Siberia, Scotland, Saxony, Bohemia, United States, Greenland. *Pot-stone*, or *lapis ollaris*, is a coarse and indistinctly granular variety, which, from its softness and tenacity, may be readily turned. It is used for the manufacture of cooking utensils and other vessels, for fire stones in furnaces, in powder for diminishing friction in machinery, and for removing oil stains from cloth.

Chlorite.—*Talk Chlorite, Ripidolith, Prismatic Talk Glimmer.*—A hydrosilicate of alumina and magnesia. **rhombohedral.** H 1·0 — 1·5 G 2·78 — 2·96. Case 32. Transparent, translucent. *Lus.* pearly. *Col.* green, blue, red. *Str.* green. In thin leaves, flexible; not elastic. B. fusible on the edges. Decomposed by strong sulphuric acid.

Found in granite, gneiss, diabase, and slaty rocks. The Ural, Norway, Sweden, Switzerland, the Tyrol, Saxony, Cornwall, Arran, Bute. Derives its name from χλωρος, *green.*

Ripidolite.—*Chlorite, Prismatic Talk Glimmer, Kämmererite, Leuchtenbergite, Pennine, Rodochrome.*—A hydrosilicate of alumina and magnesia. **Rhombohedral.** H 2·0 — 3·0 G 2·615 — 2·774. Case 32. Semi-transparent, translucent. *Lus.* vitreous. *Col.* green, violet. *Str.* white. In thin leaves, flexible, but not elastic. B. fusible on the edges. Decomposed by hot sulphuric acid.

Found in beds and veins in crystalline rocks. The Tyrol, Piedmont, the Ural, Silesia, the Pyrenees, Norway, Siberia, Styria, Baltimore. The violet varieties are called kämmererite. Its name is derived from *ριπις a fan.*

Loganite.—A hydrosilicate of alumina and magnesia. **Prismatic.** H 3·0 G 2·60 — 2·64. *Frac.* uneven. Subtranslucent. *Lus.* vitreous. *Col.* brown. *Str.* grayish-white. B. infusible. Partly decomposed by acids.

Found in limestone at Ottawa in Canada.

Pyrophillite.—2 ($Al^2 O^3$ + 3 Si O^2) + 3 H O **prismatic.** H 1·0 G 2·785. Case 32. Translucent. *Lus.* pearly. *Col.* green, white. *Str.* white. B. fusible with difficulty. Partially decomposed by sulphuric acid.

Found in granite. The Ural, Belgium, the Brazils, United States.

Amphibole.—*Hornblende, Hemiprismatic Augite Spar, Smaragdite, Tremolite, Actinolite, Asbestos, Strahlstein, Raphilite, Cummingtonite.*—3 (R O + S O^2) + (2 R O + S O^2), where R is Mg, Ca, and Fe. **oblique.** H 5·0 — 6·0 G 2·90 — 3·40. Cases 33 and 34. *Frac.* imperfect, conchoidal. Slightly translucent, opaque. *Lus.* vitreous. *Col.* colourless, white, green, brown, yellow, gray, black. *Str.* grayish-white, brown. Brittle. B. fusible. Slightly soluble in hydrochloric acid.

Grammatite.—The white, green, gray, semi-transparent, and translucent varieties, found in granular limestone, granite, and marble. St. Gotthardt, Transylvania, Bohemia, the Tyrol, Sweden, France, the Banat, Massachusetts, Aberdeenshire, Iona.

Actinote.—The greenish varieties, found in beds of iron ore. Saxony, Bohemia, Norway, Sweden, the Tyrol, Styria, Moravia.

Anthophyllite.—Found in Norway, Greenland, and United States.

Mountain Wood, Mountain Cork, &c., are fibrous varieties. Found in the Tyrol, Saxony, Bohemia, Sweden, Switzerland, Spain, the United States, Scotland.

Asbestos, or *Amianthus.*—A variety in flexible slender fibres Corsica, Piedmont, Savoy, Saltzburg, the Tyrol, Dauphiné, Hungary, Silesia, United States, Cornwall, Aberdeenshire. (*ασβεστος, unconsumable*). The ancients wove this substance into cloth, which could be purified by burning.

Common Hornblende.—In dark green or black crystals, found in beds of iron ore. Norway, Sweden, Finland, Saxony, Bohemia, the Tyrol, Carinthia.

Basaltic Hornblende.—Black opaque crystals, embedded in basaltic rocks. Bohemia and Spain.

Pargasite.—*Hornblende.*—**Oblique.** H 5·0 — 6·0 G 3·07 — 3·08. Case 33. *Frac.* conchoidal. Translucent. *Lus.* vitreous. *Col.* bluish-green. *Str.* white. B. fusible.

Found in limestone at Pargas in Finland.

Masonite.—*Chlorite Spar, Chloritoid, Barytophyllite.*—A hydrosilicate of alumina and iron. H 5·5 — 6·0 G 3·45 — 3·55. Case 33. Translucent in thin leaves. *Lus.* pearly. *Col.* blackish-green. *Str.* greenish-white. Brittle. B. fusible on the edges. Not acted on by acids.

Found in chlorite slate. Siberia, Rhode Island, the Tyrol, the Ural.

Arfvedsonite.—*Peritomous Augite Spar, Ægirine.*—**Oblique.** H 6·0 G 3·328 — 3·44. Case 33. *Frac.* imperfect, conchoidal. Opaque. *Lus.* vitreous. *Col.* black. *Str.* green. B. fusible.

Found in slate rock and beds of iron ore. Greenland, Norway, Arendal.

Krokydolite.—*Blue Asbestos.*—A hydrosilicate of iron. H 4·0 — 4·5 G 3·2 — 3·3. Case 34. Delicate fibres like asbestos. Translucent. *Lus.* silky. *Col.* indigo-blue. Tough, elastic, flexible. B. fusible. Not acted on by acids.

Found in syenite and quartz. South Africa, Norway, Greenland, Saltzburg. Derives its name from *κροκυς a flock of wool*, on account of the slender threads into which it is divisable.

Augite.—*Pyroxene, Diopside, Amianth, Malacolith, Paratomous, Augite Spar, Alalite, Baikalite, Jeffersonite, Goccolite, Sahlite, Omphazite, Pyrgome, Fassite.*—($Ca\ O + Si\ O^2$) + ($R\ O + Si\ O^2$), where R consists essentially of Mg and Fe. **oblique.** H 5·0 — 6·0 G 3·2 — 3·4. Case 34. *Frac.* conchoidal, uneven. Transparent, opaque. *Lus.* vitreous. *Col.* colourless, white, green, gray, black. *Str.* white, gray. Brittle. B. fusible. Slightly affected by acids.

Found in basalt, lava, limestone, meteoric stones, and slag of iron furnaces. Bohemia, France, Vesuvius, Teneriffe, Scotland, Finland, North America, Switzerland, Sweden, Norway. Can be formed artificially by fusing silica, lime, and magnesia in the right proportions. Some of the transparent varieties, when cut and polished, form handsome ornamental stones, of colours varying from the emerald to the yellow topaz.

Hypersthene.—*Paulite, Prismatoidal Schiller Spar, Labrador Hornblende, Diallage Metalloide.*—$RO + Si\ O^2$, where R is Mg and Fe. **oblique.** H 6·0 G 3·39. Case 34. *Frac.* uneven, opaque, translucent on the edges. *Lus.* pearly-vitreous. *Col.* grayish or greenish black. *Str.* greenish gray. B. fusible. Insoluble in acids.

Found imbedded in a greenstone rock, also associated with Labrador felspar. Labrador, Greenland, Norway, Skye, Saxony, Bohemia, the Tyrol, Sweden, Silesia, Berlin. Distinguished from bronzite by its cleavage. Cut and polished it presents a beautiful red colour and pearly lustre.

Diallage.—*Prismatic Schiller Spar, Diatomous Schiller Spar.*—**Oblique.** H 4·0 G 3·2 — 3·3. Case 34. *Frac.* uneven. Opaque. *Lus.* pearly or silky. *Col.* gray, greenish, brown. *Str.* white. B. fusible. Insoluble in acids.

Found with amphibole. The Hartz, Silesia, Apennines, the Ural.

Ilvaite.—*Lievrite, Yenite, Fer Calcaréo Siliceux, Diprismatic Iron, Ore.*—($Fe^2\ O^3 + Si\ O^2$) + 2 ($R^2\ O + Si\ O^2$), where R is Ca and Fe. **prismatic.** H 5·5 — 6·0 G 3·989 — 4·015. Case 34. *Frac.* imperfect conchoidal. Opaque. *Lus.* imperfect metallic. *Col.* black, inclining to gray, brown, and green. *Str.* black. Brittle. B. fusible. Decomposed by warm hydrochloric acid, leaving a jelly of silica.

Found imbedded in augite in Elba, Norway, Silesia, Moravia, Siberia, Greenland.

Acmite.—*Paratomous Augite Spar.*—($2\ Fe^2\ O^3 + 3\ Si\ O^2$) + 2 ($Na\ O + Si\ O^2$). **oblique.** H 6·0 — 6·5 G 3·53 — 3·55. Case 34. *Frac.* imperfect conchoidal.

Nearly opaque. *Lus.* vitreous. *Col.* brownish-black or reddish-brown. *Str.* greenish-gray. B. fusible. Partially decomposed by hydrochloric and sulphuric acids.

Found in granite and syenite. Norway. A scarce mineral. Derives its name from *ακμη, a point*, on account of the form of its crystals, some of which have been found a foot in length.

Epidote.—*Prismatoidal Augite Spar, Pistacite, Thallite, Withamite, Akanticon, Scorza, Delphinite, Arendalite, Thulite, Puschkinite, Achmatite.*—(3 Ca O + 2 Si O^2) + 2 (R^3 O^3 + Si O^2), where R^3 is Al, Fe^2, or Mn^2. **oblique.** H 6·5 G 3·0 – 3·5. Case 35. *Frac.* uneven, semi-transparent. *Lus.* vitreous. *Col.* green, yellow, brown, red, black. *Str.* gray. Brittle. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Occurs in granite, syenite, trap, porphyry, and slate rocks. Norway, Sweden, the Alps, Dauphiné, the Ural, Pyrenees, Bohemia, Finland, Greenland, Norway.

Zoisite.—**Oblique.** Case 35. *Lus.* vitreous. *Col.* grayish-white, yellowish-gray, brown, green. B. fusible.

Found in Carinthia, the Tyrol, Saltzburg, Bayreuth, Bavaria, the Ural.

Somervillite.—*Melilite, Humboldtilite, Zurlite.*—2 (2 RO + 2 Si O^2) + (R′ O^3 + Si O^2), where R is Ca, Mg, Na, and K, and R′ is Al and Fe^2. **pyramidal.** H 5·0 – 5·5 G 2·90 – 3·104. Case 35. *Frac.* conchoidal, uneven, semi-transparent. Opaque. *Lus.* vitreous. *Col.* white, green, yellow, brown. *Str.* white. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found with calcite and in lava. Monte Somma and Capo di Bove.

Bastite.—*Schiller Spar, Metalloid Diallage.*—4 (RO + Si O^2) + (Mgo + 4HO) where R is Mg, Ca and Fe. H 3·5 – 4·0 G 2·6 2·8. Case 35. *Frac.* uneven. Translucent. *Lus.* pearly. *Col.* green, brown, yellow. *Str.* greenish-white. B. fusible on the edges. Decomposed by sulphuric acid.

Found in the euphotide of the Hartz.

Babingtonite.—*Axotomous Augite Spar.*—**anorthic.** H 5·5 – 6·0. G 3·355 – 3·406. Case 35. *Frac.* imperfect, conchoidal. *Lus.* vitreous. *Col.* black. *Str.* greenish-gray. Brittle. B. fusible. Decomposed by boiling hydrochloric acid.

Found in magnetite, quartz, felspar, and prehnite. Norway, Shetland, New York, Massachusetts.

Idocrase.—*Pyramidal Garnet, Vesuvian, Egeran, Loboit, Frugardit, Cyprine.*—($3CaO + 2SiO^2$) + ($AlO^3 + SiO^2$). **pyramidal.** H 6·5 G 3·35 – 3·45. Case 35. *Frac.* imperfect conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* green, yellow, brown, black. *Str.* white. B. fusible. Imperfectly decomposed by hydrochloric acid.

Found in dolomite, serpentine, and limestone. The Ural, St. Gotthardt, Norway, Bohemia, Sweden, Finland, the Pyrenees, Saxony, Ireland, Spain, North America. At Naples and Turin ornaments are formed of idocrase, which takes a good polish, and are sold under the denomination of hyacinth, crysolite, &c.

Uwarowite.—*Chrome and Lime Garnet.*—($3CaO + 2SiO^2$) + ($Cr^2O^3 + SiO^2$). **cubic.** H 7·5 – 8·0 G 3·418. Case 36. *Frac.* imperfect, conchoidal. Translucent. *Lus.* vitreous. *Col.* emerald-green. *Str.* greenish-white. B. infusible.

Found in the Ural,

Garnet.—*Allochroit, Dodecahedral Garnet.*—$(3RO + 2SiO^3) + (R^1O^8 + SiO^2)$, where R is Ca, Mg, Fe; and R^1 is Al, Fe^2. **cubic.** H 6·5 – 7·5 G 3·1 – 4·3. Case 36. *Frac.* conchoidal. Transparent, opaque. *Lus.* vitreous. *Col.* red, brown, yellow, white, green, black. *Str.* white, gray. B. fusible. Soluble imperfectly in hydrochloric acid.

Almandine, the transparent red garnet, found in sand, alluvial soil, and gneiss. Pegu, Ceylon, Hindostan, Brazils.

Common Garnet, found in Saxony, Norway, Sweden, Finland, Hungary, Stiria, the Tyrol, Moravia, Silesia, Siberia.

Calophonite, granular brown garnet. Arendal and North America.

Grossular Garnet and *Pyrenaite*, a light-green variety. Kamtschatka.

Melanite, black garnet. Vesuvius, Rome, Norway, the Pyrenees.

Topazolite, honey-yellow garnet. Piedmont.

Essonite or *Cinnamon Stone*, *Romanozovite*, reddish-yellow garnet. Ceylon, Egypt, Finland, Piedmont.

Pyrope, dark-red variety of garnet. Saxony, Bohemia, Ceylon.

When the garnet is of a rich colour and free from flaws, it forms a valuable gem; it may be distinguished from corundum or spinel by its colour being duller. Coarse garnets reduced to a fine powder, are used instead of emery for polishing metals.

Gehlenite.—*Stylobite, Pyramidal Adiaphane Spar.*—$(3\ CaO + SiO^2) + (AlO^3 + SiO^2)$. **pyramidal.** H 5·5 – 6·0 G 2·99 – 3·10. Case 36. *Frac.* imperfect conchoidal. Translucent on the edges. *Lus.* resinous. *Col.* gray, brown, green. *Str.* white. B. fusible with great difficulty. Decomposed by warm hydrochloric acid, leaving a jelly of silica.

Found imbedded in calcite, near Vigo; also in the slags of iron furnaces.

Cordierite.—*Iolite, Pelioma, Prismatic Quartz, Dichroite, Steinheilite.*—$(Al\ O^6 + 3\ Si\ O^2) + 2\ (Mg\ O + Si\ O^2)$. **prismatic.** H 7·0 – 7·5 G 2·600 — 2·718. Case 36. *Frac.* conchoidal. Transparent. *Lus.* vitreous. *Col.* blue, inclining to gray or black. *Str.* white. B. fusible on the edges. Imperfectly decomposed by acids.

Found in gneiss. Spain, Bavaria, Finland, Norway, Sweden, Greenland, Siberia, North America, Ceylon. *Pinite, Gieseckite, Oosite, Killinite, Fahlunite, Triclasite, Bonsdorffite, Esmarkite, Aspasiolite, Pyrargyllite, Chlorophyllite, Gigantolite, Praseolite, Iberite, Weissite*, are supposed to be *Cordierite*, more or less changed by decomposition. A transparent variety from Ceylon, of an intense blue colour, is called *Sapphire d'eau;* it is inferior in hardness and lustre to the sapphire, and its specific gravity is less.

Sordawalite.—Massive. H 4·0 — 4·5 G 2·55 — 2·62. Case 36. *Frac.* conchoidal. Opaque. *Lus.* resinous. *Col.* black, brown, green. *Str.* brown. Brittle. B. fusible. Imperfectly decomposed by acids.

Found at Sordawla in Finland.

Bragationite.—Oblique. H 6·3 G 4·115. *Frac.* uneven. Opaque. *Lus.* vitreous. *Col.* black. *Str.* dark brown. B. fusible.

Found at Slatoust in the Ural.

Bucklandite.—*Dystomic Augite Spar.*—$(3\ Fe\ O + 2\ Si\ O^2) + 2\ (Fe^2\ O^3 + Si\ O^2)$. **oblique.** H 6·0 G 3·865. Case 36. *Frac.* uneven. Opaque. *Lus.* vitreous. *Col.* dark brown, black. *Str.* gray. B. fusible.

Found in volcanic rocks and granite. Arendal, Laach, Siberia. A very rare mineral, having a general resemblance to augite.

Staurolite.—*Grenatite, Prismatic Garnet, Prismatoidal Garnet.*—$R^2 O^3 + Si O^2$ where R is Al and 2 Fe. **prismatic.** H 7·0 — 7·5 G 3·52 — 3·79. Case 31. *Frac.* conchoidal, uneven. Translucent. *Lus.* vitreous, inclining to resinous. *Col.* reddish-brown, blackish-brown. *Str.* white. B. nearly infusible. Partially decomposed by sulphuric acid.

Found in mica, talc, or clay slate, rarely in gneiss. St. Gotthardt, Transylvania, Moravia, Spain, Var, Hebrides, Aberdeenshire, the Ural, New England. The crystals of this mineral are sometimes curiously associated with those of Kyanite, the crystals of the two substances being disposed sometimes parallel, as if forming one crystal, and sometimes at right angles to the axis. Named from *σταυρος a cross.*

Karpholite.—A hydrosilicate of manganese. H 5·0 — 5·5 G 2·935. Case 36. Feebly translucent. Opaque. *Lus.* vitreous. *Col.* yellow. *Str.* white. B. fusible. Scarcely acted on by hydrochloric acid.

Found in acicular and capillary crystals in granite. Bohemia. Named from *καρφος, a straw,* on account of its colour.

Emerald.—*Beryl, Aquamarine, Davidsonite, Goshenite, Dirhombohedric Smaragd.*—$(Al O^2 + 3 Si O^2) + 3 (G O + Si O^2)$. **rhombohedral.** H 7·5 – 8·0 G 2·67 – 2·75. Case 37. *Frac.* conchoidal, uneven. Transparent, translucent. *Lus.* vitreous. *Col.* green in the emerald, colourless blue, yellow and red for the beryl. *Str.* white. B. fusible on the edges.

The *Emerald* is found in Peru, Egypt, Siberia, and Norway.

The *Beryl*, or *aquamarine*, in Saxony, Bohemia, Bavaria, Elba, France, Norway, Sweden, Finland, Siberia, North America, Brazils, Ireland, and Aberdeenshire. The emerald is most valuable as a gem.

Euclase.—*Prismatic Smaragd.*—$(Al O^3 + 3 Si O^2) + 6 (2 G O + Si O^2)$. **Oblique.** H 7·5 G 3·0 — 3·1. Case 37. *Frac.* conchoidal. Transparent, semi-transparent. *Lus.* vitreous. *Col.* green, yellow, blue, very pale. *Str.* white. B. fusible. Not acted on by acids.

A rare mineral; found in chlorite slate, mica and fluor. Brazils, Connecticut, Peru. Derives its name from *εὖ easily,* and *κλαω to break,* on account of its brittleness.

Phenakite. — *Rhombohedral Smaragd.* — $2 G O + Si O^2$. **rhombohedral.** H 7·5 – 8·0 G 2·96 — 3·0. Case 37. *Frac.* conchoidal, uneven. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, yellow, brown. B. Infusible. Insoluble in acids.

Found with iron ore, emerald, green felspar, and topaz. Alsace and Siberia. Derives its name from *φεναξ a deceiver,* on account of its having been mistaken for quartz.

Helvin.—*Tetrahedral Garnet.*—$3 (2 RO + Si O^2) + Mn S$ where R is Fe, Mn, and G. **cubic.** H 6·0 — 6·5 G 3·1 — 3·3. Case 37. *Frac.* uneven. Translucent on the edges. *Lus.* vitreous. *Col.* brown, yellow, green. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid leaving a jelly of silica.

A very rare mineral; found in gneiss. Saxony, Norway, and Bavaria. Named from *ἥλιος the sun,* on account of its yellow colour.

Gadolonite.—*Hemiprismatic Melane ore, Ytterbite.* **prismatic.** H 6·5 G 4·2 — 4·4. Case 37. *Frac.* conchoidal, uneven. Opaque. *Lus.* vitreous. *Col.* black, seldom red. *Str.* greenish-gray. B. infusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in granite, gneiss, syenite and trap. Stockholm, Fahlun, Ceylon, Galway in Ireland. Yttria was first discovered by Gadolin in this ore.

Allanite.—*Orthite, Cerine, Bagrationite, Uralorthite, Xanthortite, Pyrorthite, Black Siliceous Oxide of Cerium, Tetarto Prismatic Melane Ore.*—$(3\ R\ O + 2\ Si\ O^2) + (R^1\ O^3 + Si\ O^2)$ where R is Ca, Ce, and Fe, and R′ is Fe^2 or Al. **oblique.** H 6·0 G 3·1 —4·2. Case 38. *Frac.* conchoidal. Opaque. *Lus.* imperfect, metallic. *Col.* black, brown, green. *Str.* greenish or brownish-gray. Brittle. B. fusible.

Found in granite. Greenland, Norway, Sweden, the Ural.

Tscheffkinite.—H 5·3 G 4·508 — 4·549. Case 37. *Frac.* conchoidal. Almost opaque. *Lus.* vitreous. *Col.* black. *Str.* brown. B. fusible. Soluble in hydrochloric acid, leaving a jelly of silica.

Found with felspar in the Ilmen mountains near Miask.

Rutile.—*Oxide of Titanium, Peritomous Titanium Ore, Titanschorl, Nigrine, Gallicinite, Sagenite, Crispite.*—$Ti\ O^2$. **pyramidal.** H 6·0 — 6·5 G 4·22 — 4·30. Case 37. *Frac.* conchoidal, uneven. Translucent, opaque. *Lus.* adamantine. *Col.* reddish-brown, red, yellow, black. *Str.* very light brown. B. infusible. Soluble with difficulty, when powdered, in hot concentrated sulphuric acid.

In veins and beds with quartz, felspar, and in alluvium. Hungary, Styria, Norway, the Tyrol, Bohemia, Switzerland, Ceylon, France, Siberia, North and South America, Fife, Perthshire, Shetland. Used in painting porcelain.

Anatase.—*Pyramidal Titanium Ore, Octahedrite, Oisanite.*—$Ti\ O^2$. **pyramidal.** H 5·5 — 6·0 G 3·83 — 3·93. Case 37. *Frac.* conchoidal. Semi-transparent, translucent. *Lus.* adamantine. *Col.* blue, black, red, yellow, brown. *Str.* white. Brittle. B. infusible. Not decomposed by acids.

Found in granite and mica slate. Dauphiné, Switzerland, Cornwall, Spain, the Ural, Norway, Brazils. The crystals from the Brazils resemble the diamond so much in colour and general appearance, as often to deceive lapidaries and mineral dealers.

Pyrochlore.—*Microlite, Octahedral Titanium Ore.*—**Cubic.** H 5·3 — 5·5 G 4·19 — 4·33. Case 37. *Frac.* conchoidal. Opaque, translucent on the edges. *Lus.* resinous. *Col.* dark brown. *Str.* light brown. Rather brittle. B. fusible. Decomposed in powder by concentrated sulphuric acid.

Found in syenite and granite. Norway, the Ural.

Sphene.—*Titanite, Brown and Yellow Menachine Ore, Calcareo-siliceous Titanium, Greenovite, Lederite, Pictite, Arpidelite, Prismatic Titanium Ore.*—$(2\ Ca\ O + Si\ O^2) + (2\ Ti\ O + Si\ O^2)$. **oblique.** H 5·0 — 5·5 G 3·3 — 3·7. Case 37. *Frac.* imperfect, conchoidal. Transparent. *Lus.* adamantine. *Col.* yellow, green, brown, red. B. fusible on the edges. Decomposed by sulphuric acid.

Found in granite, syenite, gneiss, slate, marble, basalt, and lava. Piedmont, the Tyrol, the Pyrenees, the Ural, Norway, Sweden, Bohemia, Moravia, France, Scotland, Ireland, Greenland, Brazils, United States, Greek Islands. Derives its name from *σφην a wedge*, on account of the shape of its crystals.

Brookite.—*Prismatic Titanium Ore, Juranite, Arkansite, Eumanite.*—$Ti\ O^2$. **prismatic.** H 6·0 G 4·125 — 4·170. Case 37. *Frac.* uneven. Translucent, opaque. *Lus.* metallic. *Col.* yellowish-brown, reddish-brown, hyacinth-red. *Str.* yellowish-white. Brittle. B. infusible. In powder soluble in hot concentrated sulphuric acid.

Dauphiné, Switzerland, the Ural, Caernarvonshire, Ætna, Arkansas. It is not a common mineral.

Perowskite.—($CaO + TiO^2$). **cubic.** H 5·8 G 3·99 — 4·017. Case 37. Opaque. *Lus.* adamantine. *Col.* black, reddish-brown. *Str.* grayish-white. B. infusible. Acted on very feebly by hydrochloric acid.

Found in limestone and chlorite slate. Vogsburg and the Ural.

Mengite.—Supposed to contain oxides of iron and manganese, titanic acid and zirconia. **prismatic.** H 5·0 — 5·5 G 5·43. *Frac.* uneven, conchoidal. Opaque. *Lus.* metallic. *Col.* iron-black. *Str.* brown. B. infusible. Soluble in hot concentrated sulphuric acid.

Found in albite in Siberia.

Polymignite.—*Prismatic Melane Ore.*—**Prismatic.** H 6·5 G 4·75 — 4·81. Case 37. *Frac.* conchoidal. Opaque. *Lus.* metallic. *Col.* iron-black. *Str.* dark brown. Brittle. B. infusible. Decomposed in powder by concentrated sulphuric acid.

Found in syenite and basalt in Norway.

Fergusonite.—*Pyramidal Melane Ore.*—($6 R O + Ta O^3$), where R is Y, Ce, and Zr. **pyramidal.** H 5·5 — 6·0 G 5·8 — 5·9. Case 37. *Frac.* conchoidal. Opaque. *Lus.* imperfect, metallic. *Col.* blackish-brown. *Str.* pale brown. Brittle. B. infusible.

Found in quartz in Greenland.

Polykrase.—**Prismatic.** H 6·0 G 5·105. *Frac.* conchoidal. Translucent in thin fragments. *Lus.* metallic. *Col.* black. *Str.* grayish-brown. B. infusible. Decomposed by hot sulphuric acid.

Found in granite in Norway.

Æschynite.—**Prismatic.** H 5·5 G 5·1 — 5·2. Case 37. *Frac.* imperfect conchoidal. Faintly translucent on the edges. Opaque. *Lus.* imperfect metallic. *Col.* iron, black, brown. *Str.* yellowish-brown. Brittle. B. nearly infusible. Partially decomposed by concentrated sulphuric acid.

Found in a rock consisting of felspar, albite, and mica, near Miask, in the Ural.

Malacone.—**Pyramidal.** H 6·0 G 3·903 — 3·913. *Frac.* conchoidal. *Lus.* vitreous. B. infusible. Decomposed by hot sulphuric acid.

Found at Hitteröe in Norway.

Œrstedite.—**Pyramidal.** H 5·5 G 3·629. Case 37. Translucent. *Lus.* adamantine. *Col.* yellowish-brown. B. infusible.

Found at Arendal in Norway.

Mosandrite.—H 4·0 G 2·93. Case 37. Translucent in thin fragments. *Lus.* resinous. *Col.* brown. *Str.* grayish-brown. B. fusible. Decomposed by hydrochloric acid.

Found in syenite. Norway.

Keilhauite.—*Yttrotitanite.* H 6·5 G 3·69. Case 37. *Frac.* conchoidal. Translucent. *Lus.* vitreous. *Col.* brownish-black. *Str.* grayish-brown. B. fusible. Decomposed by hydrochloric acid.

Found at Buön in Norway.

Iserine.—*Hexahedral Iron Ore, Oxidulous Titanitic Iron.*—$Fe O + R^2 O^3$, where

R is Fe or Ti. **cubic.** H 6·0 – 6·5 G 4·86 — 5·10. Case 37. *Frac.* conchoidal Opaque. *Lus.* metallic. *Col.* iron-black. *Str.* black. Brittle. Magnetic. B. infusible

Found in basalt and dolorite, also as sand in alluvium. Saxony, Upper Lusatia, Unkel, the Rhine, France, Calabria. Distinguished from nigrine, a variety of rutile, by its inferior hardness and black streak.

Ilmenite.—*Titanitic Iron, Axotomous Iron Ore, Crichtonite, Kibdelophane, Menaccanite.*—Ti O^3 with Fe O^3 in various proportions. **rhombohedral.** H 5·0 — 6·0 G 4·66 — 5·31. Case 37. *Frac.* conchoidal. Opaque. *Lus.* imperfect metallic. *Col.* iron-black. *Str.* black, brown. Brittle. B. infusible.

Found imbedded in serpentine, and also disseminated through sand. Saltzburg, Siberia, France, Bohemia, St. Domingo.

Niobite.—*Tantalite, Baierine, Torrelite, Hemiprismatic Tantal Ore, Columbite.* **prismatic.** H 6·0 G 5·32 — 6·39. Case 38. *Frac.* imperfect conchoidal. Opaque. *Lus.* imperfect metallic. *Col.* black. *Str.* dark-brown or black. B. infusible. Not acted on by acids.

Found in granite. Rabenstein, Ilmen, Connecticut, Massachusetts, and New Hampshire.

Tantalite.—*Prismatic Tantalum Ore, Columbite.*—Fe O + Ta O^3. **prismatic.** H 6·0 — 6·5 G 7·0 — 8·0. Case 38. *Frac.* conchoidal. Opaque. *Lus.* imperfect metallic. *Col.* iron-black. *Str.* brown. B. fusible. Not acted on by acids.

Found in granite, felspar, and quartz. Sweden, Bavaria, Bohemia, Connecticut, Massachusetts.

Yttrotantalite.—(3 RO + Ta O^3), where R is Y, Ca, Fe, U. H 5·0 — 5·5 G 5·39 — 5·88. Case 38. *Frac.* conchoidal. Opaque. *Lus.* imperfect metallic. *Col.* black, brown. *Str.* gray or white. B. infusible. Not acted on by acids.

Found in indistinctly formed crystals, in felspar and granite. Sweden, Fahlun, and the Ural.

Samarskite.—*Uranotantal, Yttro-ilmenite.* **prismatic.** H 5·5 G 5·617 — 5·715. Case 38. *Frac.* conchoidal. Opaque. *Lus.* imperfect metallic. *Col.* black. *Str.* dark-brown. B. fusible on the edges. Soluble in hydrochloric acid.

Found in felspar. Ilmen, near Miask.

Wohlerite.—H 5·5 G 3·41. Case 38. *Frac.* conchoidal. Translucent. *Lus.* vitreous. *Col.* yellow, brown, gray. *Str.* yellowish-white. B. fusible. Decomposed by warm concentrated hydrochloric acid.

Found in tabular and columnar crystals in syenite. Norway.

Euxenite.—H 6·5 G 4·6. Case 38. *Frac.* imperfect conchoidal. Translucent. *Lus.* resinous. *Col.* brownish-black. *Str.* reddish-brown. B. infusible. Not acted on by acids.

A rare mineral, found in Norway, named from *εὔξενος a stranger*, on account of its rarity.

Schorlomite.—*Ferrotitanite.*—2(RO + SiO^2) + (2RO + TiO^2), where R is Fe, Ca, and Mg. **amorphous.** H 7·5 G 3·783 — 3·807. *Frac.* conchoidal. Opaque. *Lus.* vitreous. *Col.* black, iridescent. B. fusible on the edges. Decomposed partially by hydrochloric acid.

Found massive with brookite. Arkansas.

Antimonocher.—*Cervantite, Antimonial Ochre, Antimonial Oxide.*—$SbO^3 + SbO^5 + 2HO$. **amorphous.** Very soft. G 5·28. Case 38. *Frac.* uneven, earthy. Opaque. *Lus.* dull. *Col.* yellow. *Str.* yellowish-white, shining. Brittle. B. volatilizes.

Found with antimonite, in Spain, Hungary, Bavaria, Mexico, Padstow, Cornwall.

Kermes.—*Red Antimony, Antimony Blende, Prismatic Purple Blende.*—$(SbO^3 + 2SbS^3)$. **oblique.** H 1·5 G 4·5 – 4·6. Case 38. Faintly translucent. *Lus.* adamantine. *Col.* cherry-red. *Str.* red. Sectile. B. fusible. Soluble in hydrochloric acid.

Found in crystalline slate and transition rocks. Saxony, Bohemia, Hungary, Dauphiné.

Zundererz.—An impure arsenical sulphuret of antimony and lead. *Col.* dirty red.

Found in capillary crystals interlaced, and presenting the appearance of flakes of tinder. The Hartz.

Valentinite.—*Exitèle, Oxide of Antimony, White Antimony, Prismatic Antimony Baryte.*—SbO^3. **prismatic.** H 2·5 – 3·0 G 5·566. Case 38. Semi-transparent, translucent. *Lus.* adamantine. *Col.* white, gray, yellow, brown, red. *Str.* white. Sectile. B. fusible. Soluble in nitro-muriatic acid.

Found in Bohemia, Saxony, Hungary, Nassau, Dauphiné. Oxide of antimony, crystallized artificially, is dimorphous; the crystals belonging to the cubical or prismatic system, according as they are formed at a high or low temperature.

Scheelite.—*Tungstate of Lime, Tungsten, Pyramidal Scheel Baryta.*—$CaO + WO^3$. **pyramidal.** H 4·5 G 5·9 — 6·22. Case 38. *Frac.* imperfect conchoidal. Semi-transparent, translucent on the edges. *Lus.* vitreous. *Col.* white, gray, yellow, brown, orange, red, green. *Str.* white. Brittle. B. fusible. Decomposed when in powder by warm hydrochloric and nitric acids.

Found in gold, tin, and copper mines. Bohemia, Saxony, Cornwall, Cumberland, Connecticut, Hungary, France, the Hartz, Siberia, Chili.

Wolfram.—*Tungstate of Iron, Prismatic Scheel Ore.*—$(RO + WO^3)$, where R is Fe and Mn. **prismatic.** H 5·5 G 7·0 – 7·5. Case 38. *Frac.* uneven. Opaque. *Lus.* adamantine. *Col.* brownish-black. *Str.* brown, black. Slightly magnetic. B. fusible. Decomposed by hydrochloric acid.

Found in veins of quartz and granite. Bohemia, Saxony, France, the Hartz, Cornwall Cumberland, Hebrides, Ceylon, Siberia, Connecticut, South America.

Stolzite.—*Tungstate of Lead, Scheel Lead, Dystomous Lead Baryta.*—$PbO + WO^3$. **pyramidal.** H 3·0 G 7·9 — 8·09. Case 38. *Frac.* conchoidal. Semi-transparent. *Lus.* resinous. *Col.* gray, brown, yellow, green. *Str.* grayish-white. Brittle. B. fusible. Soluble in nitric acid.

Found with quartz and mica, in the tin mines of Zimmwald, in Bohemia. Carinthia, Chili.

Vanadinite.—*Vanadiate of Lead, Johnstonite.*—$PbCl + 2PbO + (3PbO + 3VO^3)$. **rhombohedral.** H 3·0 G 6·83 – 6·89. Case 38. *Frac.* conchoidal. Feebly translucent. Opaque. *Lus.* vitreous. *Col.* yellow, brown, green, white. *Str.* white, yellow. B. fusible. Soluble in nitric acid.

Found in Mexico, the Ural, and Dumfriesshire.

Dechenite.—($PbO + VO^3$). H 4·0 G 5·81. *Lus.* greasy. *Col.* dull-red. *Str* yellowish. B. fusible.

Found in Bavaria.

Volborthite.—*Vanadiate of Copper.*—$4CuO + VO^3 + HO$, part of the Cu replaced by Ca. **rhombohedral.** H 3·0 — 3·5 G 3·459 — 3·860. Case 38. Translucent. *Lus.* pearly. *Col.* green, gray. *Str.* yellowish-green.

Found in the permian formation. Ingowskoi, Thuringia.

Molybdanocher.—*Oxide of Molybdenum, Molybdic Acid.*—$Mo\ O^3$. Earthy. Case 39. Opaque. *Lus.* dull. *Col.* orange-yellow. B. fusible. Soluble in hydrochloric acid, in potash, and in ammonia.

Found with molybdanite. Norway, Scotland, and the Tyrol.

Wulfenite.—*Molybdate of Lead, Yellow Lead Ore, Carinthite, Pyramidal Lead Baryta.*—$PbO + MoO^3$. **pyramidal.** H 3·0 G 6·3 — 6·9. Case 39. *Frac.* conchoidal. Transparent, translucent on the edges. *Lus.* resinous. *Col.* colourless, yellow, green, red, gray, brown. *Str.* white. Brittle. B. fusible. Decomposed by acids.

Found in crystals and massive, and in lead mines. Carinthia, Austria, Hungary, the Banat, the Tyrol, Saxony, Bavaria, Massachusetts, Pennsylvania, Mexico.

Wolchonskoite.—(A hydrosilicate of chrome?) H 2·0 — 2·5 G 2·213 — 2·303. Case 39. *Frac.* conchoidal. Opaque. *Lus.* dull. *Col.* green. *Str.* lighter green. B. infusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in veins and nodules. Perm in Russia.

Chromochre.—Massive and investing other minerals. Case 39. Opaque. *Lus.* dull. *Col.* green.

Found in conglomerate and porphyry. France, Sweden, Silesia.

Lehmannite.—*Chromate of Lead, Red Lead Ore, Hemiprismatic Lead Baryta, Kalochrome, Crocoisite, Krokoite.*—$PbO + CrO^3$. **oblique.** H 2·5 — 3·0 G 5·9 — 6·1. Case 39. *Frac.* conchoidal, uneven. Translucent. *Lus.* adamantine. *Col.* red. *Str.* orange. Sectile. B. fusible. Decomposed by warm hydrochloric acid.

Found with quartz in granite and talcose slate. Siberia, the Ural, Brazils.

Phœnicite.—*Melanochroite, Phönikochroit, Phönicit.*—$3\ PbO + 2\ CrO^3$ H 3·0 — 3·5 G 5·75. Translucent on the edges. *Lus.* resinous. *Col.* red. *Str.* brick-red. Slightly brittle. B. fusible. Decomposed by hydrochloric acid.

Found in veins of quartz in the Ural.

Vanquelinite.—*Chromate of Lead and Copper, Hemiprismatic Olive Malachite.*—($3\ CuO + 2\ CrO^3$) + 2 ($3\ PbO + 2\ CrO^3$). **oblique.** H 3·0 — 3·5 G 5·75. Case 39. *Frac.* flat, conchoidal. Slightly translucent. Opaque. *Lus.* waxy. *Col.* green, brown. *Str.* green. B. fusible. Soluble in nitric acid.

Found in veins of quartz. The Ural, Brazils, North America.

Chromite.—*Chromate of Iron, Octahedral Chrome Ore, Prismatic Chrome Ore.*—$RO + R'^2 O^3$, where R is Fe, Mg, or Cr, and R′ is Cr, Al, and perhaps Fe. **cubic.** H 5·5 G 4·40 — 4·59. Case 39. *Frac.* uneven, imperfect conchoidal. Opaque.

Lus. metallic. *Col.* iron-black, brownish-black. *Str.* dark-brown. Brittle. Sometimes slightly magnetic. B. infusible. Soluble in bisulphate of potash.

Found in serpentine, limestone, and in streams. France, Stiria, Banffshire, Stirlingshire, Silesia, Bohemia, Norway, Siberia, Maryland, Pennsylvania, Vermont, New Jersey, Massachusetts, Baltimore, St. Domingo. The large proportion of chrome renders this a highly valuable mineral. In combination with the oxides of other minerals it yields green, yellow, and red pigments, used in oil painting, dyeing and colouring porcelain.

Sassoline.—*Native Boracic Acid, Prismatic Boracic Acid.*—$BoO^3 + 3HO$. **anorthic**. H 1·0 G 1·48. Case 39. Transparent, translucent. *Lus.* pearly. *Col.* white, colourless, grayish-white, yellowish-white. *Str.* white, unctuous to the touch. *Taste,* acid and bitter. Soluble in water and in alcohol.

Found, mixed with sulphur, in the islands of Vulcano and Stromboli, and in the water of the hot springs of Sasso, in Tuscany. Used in the manufacture of borax.

Hayesine —*Hydroborocalcite.*—$2(CaO + BO^3) + 6HO$. Case 39. *Col.* white.

Found abundantly, in fibrous masses, on the dry plains near Iquique, in Peru.

Hydroboracite.—$(3CaO + 4BO^3) + (3MgO + 4BO^3) + 18HO$. H 2·0 G 1·9. In thin leaves translucent. *Col.* white. B. fusible. Soluble in hot hydrochloric and nitric acids.

Found in fibrous masses in the Caucasus.

Tincal.—*Borate of Soda, Prismatic Borax Salt.*—$NaO + 2BO^3 + 10HO$. **oblique**. H 2·0 – 2·5 G 1·716. Case 39. *Frac.* conchoidal. Transparent, translucent. *Lus.* resinous. *Col.* colourless, white, gray, yellow, green. *Str.* white. Rather brittle. Taste, alkaline, sweetish. B. fusible. Soluble in water.

Found on the shores of some lakes. Thibet, Nepaul, China, Ceylon, South America. Tincal, when purified, forms the refined borax of commerce. It is used as a flux in glass manufactories and in soldering.

Boracite —*Borate of Magnesia, Tetrahedral Boracite.*—$3MgO + 4BO^3$. **cubic**. H 7·0 G 2·83 — 2·98. Case 39. *Frac.* conchoidal. Transparent, translucent on the edges. *Lus.* vitreous. *Col.* white, colourless, gray, yellow, green, brown. *Str.* white. Pyroelectric. B. fusible. Soluble when in powder in hydrochloric and nitric acids.

Found in gypsum. Brunswick, Holstein, France,

Rhodizite.—$3CaO + 4BO^3$. **cubic**. H 8·0 G 3·416. Translucent. *Lus.* vitreous. *Col.* white, yellowish, grayish. Pyroelectric. B. fusible with difficulty.

Found with red tourmaline and quartz, in the Ural.

Datholite.—*Siliceous Borate of Lime, Botryolite, Humboltite, Esmarkite, Prismatic Dystome Spar.*—$(2CaO + SiO^2) + (BO^3 + SiO^2) + HO$. **prismatic**. H 5·5 G 2·8 – 3·0. Case 39. *Frac.* imperfect conchoidal. Translucent, transparent. *Lus.* vitreous. *Col.* white, inclining to green, yellow, and gray. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in slate, sandstone, serpentine, and greenstone. The Hartz, Bavaria, the Tyrol. Tuscany, Italy, Connecticut, New Jersey, and Scotland.

Tourmaline.—*Schorl, Aphrizite, Rubellite, Indicolite.*—**rhombohedral**. H 7·0 – 7·5 G 3·0 – 3·3. Case 40. *Frac.* imperfect conchoidal. Transparent, almost opaque. *Lus.* vitreous. *Col.* colourless, gray, yellow, green, blue, red, brown, black.

Str. white. Pyroelectric. B. fusible. Decomposed by concentrated sulphuric acid after fusion.

Found in gneiss, granite, mica slate, pebbles and sand of rivers. The Grimsel, Saxony, Moravia, Massachusetts, Siberia, Bothnia, Carinthia, Ceylon, Pegu, Madagascar, Brazils, the Tyrol, Devonshire, Cornwall, Sweden, Norway, Greenland, the Pyrenees, Banffshire, Elba. The black opaque varieties are called *schorl*, the blue crystals from Sweden *indicolite*, and the red varieties *rubellite*, or *siberite*. The specimen of rubellite in the British Museum, presented by the King of Ava to Colonel Symes, has been valued at £500. The blue, green, and brown transparent crystals are much prized, on account of their property of polarizing light, when cut in thin plates parallel to the axes of the hexagonal prism. Some of the transparent varieties are used as gems, and are sometimes sold for emeralds, topaz, and red sapphire. The yellow tourmaline is quite as valuable as the topaz; but the green and red are inferior to the emerald and sapphire. The specific gravity affords a ready test for their discrimination.

Axinite.—*Prismatic Axinite, Thumite, Thumerstein.*—**anorthic**. H 6·5 – 7·0 G 3·29 – 3·30. Case 40. *Frac.* conchoidal. Transparent, translucent on the edges. *Lus.* vitreous. *Col.* brown, blue, gray. Brittle. Acquires vitreous electricity by friction, pyroelectric. B. fusible. Decomposed by hydrochloric acid after fusion, leaving a jelly of silica.

Found in granite, dionite, diabase, gneiss, mica slate, and clay slate. Dauphiné, Cornwall, the Pyrenees, Savoy, St. Gotthardt, the Tyrol. Saxony, Norway, Sweden, the Ural, the Hartz. Though susceptible of a high polish, it wants the brilliancy requisite for an ornamental stone.

Natron.—*Carbonate of Soda, Hemiprismatic Natron Salt.*—$(NaO + CO^2) + 10\,HO$. **oblique**. H 1·0 — 1·5 G 1·423. Case 41. *Frac.* conchoidal, transparent, semi-transparent. *Lus.* vitreous. *Col.* colourless, white, yellow, gray. *tr.* white. Sectile. Taste alkaline, pungent. B. fusible. Soluble in water.

Hungary, the Asiatic Steppes, Bohemia, Vesuvius, Ætna, Teneriffe, Guadaloupe, Egypt.

Trona.—*Prismatoidal Trona Salt, Striated Soda.*—$(2\,NaO + 3\,CO^2) + 4\,HO$. **oblique**. H 2·5 G 2·112. Case 41. *Frac.* uneven. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray. *Str.* white. Brittle. Taste alkaline. B. fusible. Soluble in water.

Found on the banks of natron lakes, and under a stratum of clay. Egypt, Fezzan, Columbia.

Thermonatrite. — *Prismatic Carbonate of Soda.* — $NaO + CO^2 + HO$. **prismatic**. H 1·5 G 1·5 – 1·6. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, yellowish. *Str.* white. Sectile. Taste pungent, alkaline.

Found with natron. Debreczin, Vesuvius, Egypt, Asia, and America. Supposed to be the *nitre* of the Old Testament.

Alstonite.—*Right Prismatic Baryto-calcite.*—$(BaO + CO^2) + (CaO + CO^2)$ **prismatic**. H 4·0 – 4·5 G 3·65 – 3·70. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, grayish, white. *Str.* white. Soluble in acids with effervescence.

Found in veins with galena, Alston Moore and Fallowfield.

Baryto-Calcite.—*Hemiprismatic Hal-Baryta.*—$(BaO + CO^2) + (CaO\quad CO^2)$. **oblique**. H 4·0 G 3·6 – 3·7. Case 41. *Frac.* imperfect conchoidal. Transparent,

translucent. *Lus.* vitreous. *Col.* grayish, yellowish, or greenish-white. *Str.* white Brittle. B. infusible. Soluble with effervescence in hydrochloric and in nitric acids.

Found in mountain limestone. Cumberland.

Witherite.—*Carbonate of Baryta, Diprismatic Hal-Baryta.*—Ba O + C O^2. **prismatic.** H 3·0 – 3·5 G 4·2 — 4·4. Case 41. *Frac.* uneven. Semi-transparent, semi-translucent. *Lus.* vitreous. *Col.* white inclining to yellow, gray, green, and red. Brittle. B. fusible. Soluble with effervescence in dilute hydrochloric acid.

Found in transition rocks, granite and porphyry. Lancashire, Cumberland, Durham, Westmoreland, Shropshire, Flintshire, Styria, Saltzburg, Silesia, Hungary, Siberia, Sicily, Chili. Distinguished from *barytes* by its solubility in acids.

Strontianite.—*Carbonate of Strontian, Peritomous Hal-Baryta.* Sr O + C O^2. **prismatic.** H 3·5 G 3·59 — 3·65. Case 41. *Frac.* uneven. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, yellow, green. *Str.* white. Brittle. B. fusible on the edges. Soluble with effervescence in hydrochloric and nitric acids.

Found in limestone, clay, ironstone, basalt. Strontian, Leadhills, Yorkshire, Freiberg, Clausthal, Saltzburg, Westphalia, the Grisons, Giant's Causeway, Poland, New York, Peru. Strontia and all its combinations possess the property of giving a red colour to flame, and is therefore used for fire-works.

Aragonite.—*Prismatic Lime Haloide, Tarnowitzite, Satin Spar, Needle Spar, Igbite.*—Ca O + C O^2. **prismatic.** H 3·5 — 4·0 G 2·93 — 3·01. Cases 41 and 42. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, yellow, green, blue. *Str.* grayish-white. B. infusible. Soluble with effervescence in nitric and hydrochloric acids.

Found in gypsum, basaltic rocks, beds of brown iron ore, serpentine, lava, and deposited by hot springs. Aragon, Valencia, Bohemia, Baden, Hessia, Auvergne, the Tyrol, Hungary, Siberia, Greenland, Thuringia, the Hartz, Styria, Piedmont, Vesuvius, Iceland, Carlsbad, Cumberland, Carinthia, Devonshire, Buckinghamshire, Leadhills, Galloway. This mineral is named from Aragon, a province of Spain. The corralloid varieties which occur in beds of iron ore are called *Flos ferri;* and the massive, silky, fibrous variety derives the name of *Satin spar* from its appearance. Aragonite is distinguished from calcite by the form of its cleavage, and by flying into powder on being exposed to heat. When carbonate of lime crystallizes from its solution in boiling water containing carbonic acid, it forms crystals of *Aragonite;* if, however, it crystallizes from the same solution at the ordinary temperature of the atmosphere, it takes the form of *calcite.*

Calcite.—*Carbonate of Lime, Rhombohedral Lime Haloide.*—Ca O + C O^2. **rhombohedral.** H 3·0 G 2·69 — 2·75. Cases 42—46. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, blue, green, yellow, red, brown, black. *Str.* white. Brittle. B. infusible. Soluble with effervescence in hydrochloric and nitric acids.

Found in limestone and almost every kind of rock, also in cavities of amygdaloidal rocks. Iceland, the Hartz, Derbyshire, Cumberland, Prague, Carinthia, Bohemia, Saxony, France, United States, Thuringia. The beautiful transparent varieties from Iceland are called Iceland spar, and are remarkable for the beautiful manner in which they exhibit the properties of double refraction.

Schiffer Spath or *Slate Spar*, a lamellar variety of carbonate of lime, is found in Saxony, Bohemia, Norway, Cornwall, Scotland, Wicklow.

Granular Limestone and *Statuary Marble* consists of minute crystals of carbonate of lime. This substance is valued according as it is free from flaws, colour, and is capable of receiving

a good polish. Naxos, Paros, Tenedos, Carrara. Marbles variously coloured by foreign substances form the greater part of the transition rocks.

Oolite or *Roestone* consists of an aggregation of minute globular masses of carbonate of lime. The Portland and Bath stones are varieties of oolite.

Stalactites are pendulous masses of carbonate of lime, hanging from the roofs of caverns, and formed by the water trickling through the roof charged with carbonate of lime.

Tufa or *Calcareous Tuff* is a porous variety of limestone, deposited by calcareous springs. It possesses the valuable property of hardening on exposure to the air.

Chalk is a massive opaque carbonate of lime, consisting almost entirely of minute fossil infusoria.

Ankerite.—*Paratomous Lime Haloide, Rhoe Wand, Wandstein.*—**rhombohedral.** H 3·5 — 4·0 G 3·040 — 3·085. *Frac.* uneven. Translucent. *Lus.* vitreous. *Col.* yellowish, white, gray, brown. *Str.* white. Brittle. Soluble with effervescence in nitric acid.

Found in beds of mica slate. Styria. Highly prized as an iron ore and as a flux for smelting.

Dolomite—*Bitter Spar, Pearl Spar, Tharandite, Brown Spar, Miemite, Rhomb Spar, Magnesian Carbonate of Lime, Magnesian Limestone, Macrotypous Lime Haloide.*—Ca O + C O^2, Mg O + C O^2. **rhombohedral.** H 3·5 — 4·5 G 2·80 — 2·95. Case 47. *Frac.* conchoidal. Semi-transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, green, yellow, red, blue, brown, gray, black. *Str.* grayish-white. Brittle. B. infusible. Soluble in hydrochloric acid.

Forms rocks by itself, and occurs in beds in other rocks. The Apennines, the Tyrol, Switzerland, Piedmont, Tuscany, Saxony, Bohemia, Hungary, the Hartz, Norway, Sweden, Scotland, England. Better adapted for mortar than common limestone, as it absorbs less carbonic acid. The white marble of Paros and Iona belong to this species. It admits of being cut and polished, and is said to be durable.

Magnesite.—*Carbonate of Magnesia.*—Mg O + C O^2. **rhombohedral.**—H 4·5 — 5·0 G 2·88 — 3·02. Case 48. *Frac.* conchoidal. Transparent, translucent on the edges. *Lus.* vitreous. *Col.* colourless, yellow, brown, black. *Str.* white. B. infusible. Soluble in dilute sulphuric acid, and in nitric acid. Adheres to the tongue.

Found in serpentine. Sweden, Silesia, Moravia, Styria, the Tyrol, East Indies, Spain, America.

Hydromagnesite.—*Native Magnesia, Hydrocarbonate of Magnesia. Lancasterite.*—3 (Mg O + C O^2) + (Mg O + 4 H O). **oblique.** H 3·5 G 2·14 — 2·35. Case 47. Faintly translucent. *Lus.* pearly. *Col.* white, green. *Str.* white. B. infusible. Soluble in hydrochloric acid.

Found in earthy masses in serpentine. New Jersey, New York, Shetland Islands. Resembles talc, but distinguished from it by its hardness and specific gravity.

Gaylussite.—*Hemiprismatic Kouphone Haloide.*—(Na O + C O^2) + (Ca O + C O^2) + 5 H O. **oblique.** H 2·5 G 1·928 — 1·950. Case 48. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, yellow. *Str.* white. Brittle. B. fusible. Soluble in nitric or hydrochloric acid.

Found in crystals in a bed of clay at Lagunilla in Columbia; it is called *clavos* or nails by the natives, from the appearance of its crystals.

Chalybite.—*Spathose Iron, Sparry Iron, Carbonate of Oxide of Iron, Sphärosiderite, Siderite.*—Fe O + C O^2. **rhombohedral.** H 3·5 — 4·5 G 3·70 — 3·92. Case 48. *Frac.* imperfect conchoidal. Transparent, translucent. Opaque. *Lus.* vitreous. *Col.*

yellow, brown, gray, white, red. *Str.* yellowish-white. Brittle. Soluble in warm nitric acid.

Found in gneiss, slate and limestone, in metallic veins, and in cavities in trap rocks. The Hartz, Nassau, Styria, Carinthia, Westphalia, the Pyrenees, Bohemia, Saxony, Devonshire. *Clay Ironstone*, which is a mixture of chalybite and clay, is found in Staffordshire, South Wales, Bohemia, Moravia, Silesia, Poland, United States. A very valuable iron ore. The Styrian steel is obtained from the iron made from it.

Diallogite.—*Carbonate of Manganese, Red Manganese, Rhodocrosite.*—Mn O + C O^2. **rhombohedral.** H 3·5 — 4·5 G 3·43 — 3·63. Case 48. *Frac.* uneven. Slightly translucent. *Lus.* vitreous. *Col.* rose red, flesh red. *Str.* white. Brittle. B. infusible. Soluble in hydrochloric acid.

Found in gneiss, porphyry, and hematite. Saxony, Hungary, Transylvania, the Hartz, Switzerland, Ireland. Distinguished from manganese spar by its hardness. Some varieties become brown by exposure to air.

Calamine.—*Carbonate of Zinc, Zinc Spar, Rhombohedral Zinc Baryta, Smithsonite.*—Zn O + C O^2. **rhombohedral.** H 5·0 G 4·34 — 4·45. Case 49. *Frac.* uneven. Semi-transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, green, brown. *Str.* white. Brittle. B. infusible. Soluble in hydrochloric acid.

Found in the slate, transition, coal and oolite formations. Westphalia, Silesia, Carinthia, the Banat, Poland, Hungary, Servia, the Altai, Siberia, France, Belgium, United States, Scotland, Somersetshire, Derbyshire, Cumberland. Zinc is extracted from this ore.

Buratite.—*Aurichalcite, Orichalcite.*—(3 Zn O + C O^2) + (2 Cu O + C O^2) + 3 H O. H 2·0. Case 49. Translucent. *Lus.* pearly. *Col.* green. Soluble in hydrochloric acid.

Found in the Ural and in France.

Selbite.—*Carbonate of Silver, Gray Silver.*—Amorphous. *Frac.* uneven, earthy. *Lus.* dull. *Col.* gray. Soft. Sectile. B. fusible. Soluble in nitric acid.

Found in the Black Forest and Mexico.

Cerussite.—*Carbonate of Lead, Lead Spar, Diprismatic Lead Baryta.*—Pb O + C O^2. **prismatic.** H 3·5 G 6·4 — 6·6. Case 49. *Frac.* conchoidal. Transparent, translucent. *Lus.* adamantine. *Col.* colourless, white, gray, green, blue. *Str.* white. Brittle. B. fusible. Decomposed by hydrochloric acid.

Found in crystals, masses, and pseudomorphous, after other substances. Bohemia, Carinthia, Hungary, Saxony, the Hartz, Silesia, Westphalia, France, the Altai, Siberia, Devonshire, Cornwall, Cumberland, Derbyshire, Scotland. Valuable as an ore of lead; distinguished from sulphate of lead by its crystals being usually macled.

Agnesite.—*Bismutite, Carbonate of Bismuth.*—4 Bi O^3 + 3 CO^2 + 4 H O. Amorphous. H 4·0 – 4·5 G 6·909 – 7·670. Case 49. *Frac.* conchoidal. Opaque. Translucent on the edges. *Lus.* vitreous, dull. *Col.* green, yellow. *Str.* gray or white. B. fusible. Soluble in hydrochloric acid.

Found investing other minerals, and in pseudomorphous crystals. Schneeberg, Cornwall.

Lanthanite.—*Carbonate of Cerium.*—3 La O + C O^2 + 3 HO. **pyramidal.** H 2·5 – 3·0. Case 49. *Lus.* pearly. *Col.* white, gray, yellow. *Str.* white. Soluble in acids.

Found with cererite at Riddarhytta, in Sweden. An extremely rare mineral.

Parisite.—*Mussonite, Carbonate of Cerium Lanthanium and Didymium.*—**rhombohedral.** H 4·5 G 4·35. Case 49. *Frac.* small conchoidal. *Lus.* vitreous. *Col.* brown, yellow. *Str.* yellowish-white. B. infusible. Soluble with difficulty in hydrochloric acid.

Found in the emerald mines of Muzo, in New Granada.

Breunnerite.—*Brachytypous Lime Haloide, Carbonate of Magnesia and Iron.* Mg O + C O^2. **rhombohedral.** H 4·0 — 4·5 G 3·0 — 3·2. Case 49. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, yellow, brown. *Str.* grayish-white. Brittle. B. infusible. Soluble in acids.

Found in chlorite, talc, sometimes in serpentine, rarely in gypsum. The Tyrol, St. Gotthardt, Norway, United States, Shetland. Distinguished from dolomite by its crystallization, hardness, and specific gravity.

Mesitine.—*Mesitine Spar, Pistomesite.*—**rhombohedral.** H 3·5 — 4·0 G 3·35 — 3·42. Case 49. Transparent, translucent. *Lus.* vitreous. *Col.* gray, yellow, green. *Str.* white. Brittle. B. infusible. Soluble in hydrochloric acid.

Found with quartz and hematite, Piedmont and Saltzburg.

Chessylite.—*Blue Carbonate of Copper, Azurite, Lasur Malachite, Hemiprismatic Azure Malachite.*—(2 Cu O + C O^2) + (Cu O + H O). **oblique.** H 3·5 — 4·0 G 3·766 — 3·831. Case 50. *Frac.* conchoidal. Transparent, translucent on the edges. *Lus.* vitreous. *Col.* azure-blue, passing into blackish-blue. *Str.* blue. Brittle. B. fusible. Soluble in nitric acid.

Found in veins with green carbonate and red oxide of copper. Chessy, the Altai, the Banat, Servia, Poland, the Tyrol, Bohemia, Spain, Cornwall, Cumberland, Scotland, Siberia, Thuringia, Hessia, Silesia, Chili. A valuable ore of copper when found in sufficient quantity.

Malachite.—*Green Carbonate of Copper.*—(Cu O + C O^2) + (Cu O + H O). **oblique.** H 3·5 — 4·0 G 3·71 — 4·01. Case 51. *Frac.* conchoidal. Transparent, or translucent on the edges. *Lus.* adamantine. *Col.* green. *Str.* green. Brittle. B. partly infusible. Soluble in nitric acid.

Found in copper mines. Chessy, Spain, Prussia, Thuringia, the Tyrol, the Banat. Poland, Siberia, Cornwall, Wales, Ireland, Australia. Malachite has been divided into the *fibrous* and *massive*. The crystallized variety is extremely rare, and only found in minute transparent twins coating the cavities of the fibrous kinds. It is a valuable ore of copper, but is most prized by the lapidary on account of the beauty of its colour, and the high polish of which it is susceptible. The valuable vases and tables of malachite manufactured at St. Petersburgh are mostly formed of thin plates of this substance skilfully veneered.

Nitre.—*Nitrate of Potash, Saltpetre.* K O + N O^5. **prismatic.** H 2·0 G 1·933. Case 52. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, yellow. *Str.* white. Soluble in water.

Found as an efflorescence on the surface of the earth. Hungary, Podolia, Spain, Italy, France, Arabia, East Indies, Calabria, Virginia, the Brazils. It is also procured artificially from the decomposition of animal and vegetable matter. Used in the manufacture of gunpowder and of nitric acid.

Nitratine.—*Nitrate of Soda.*—(Na O + N O^5). **rhombohedral.** H 1·5 — 2·0 G 2·096. Case 52. *Frac.* conchoidal. Transparent, translucent. *Lus* vitreous, *Col.* colourless, white, gray, brown. *Str.* white. B. fusible. Soluble in water.

Found in crystals in beds several feet thick, with clay and sand, in the district of Tarapaca in Peru.

Mirabilite.—*Sulphate of Soda, Glauber Salt.*—Na O + S O^3 + 10 H O. **oblique.** H 1·5 — 2·0 G 1·481. Case 52. *Frac.* conchoidal. Transparent. *Lus.* vitreous. *Col.* colourless, white. *Str.* white. Sectile. B. fusible. Soluble in water.

Found in salt springs as an efflorescence on the soil, and dissolved in mineral waters. Austria, Saltzburg, Bohemia, the Tyrol, Hungary, Spain, the Hartz, Switzerland, Siberia, Egypt. Employed in some countries as a substitute for soda in the manufacture of glass.

Astrakhanite.—(Na O + S O^3) + (Mg O + S O^3) + 4 H O. Transparent. *Col.* colourless. Efflorescent. Soluble in water.

Found in prismatic crystals in the salt lakes of Astrakhan.

Glauberite.—*Anhydrous Sulphate of Soda and Lime, Hemiprismatic Brythine Spar, Brongniartin.*—(Na O + S O^3) + (Ca O + S O^3). **oblique.** H 2·5 — 3·0 G 2·75 — 2·85. Case 52. *Frac.* conchoidal. Semi-transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, red. *Str.* white. Brittle. B. fusible. Partially soluble in water.

Found in rock salt. Spain, Bavaria, Atacama, Chili.

Thenardite.—(Na O + S O^3). **prismatic.** H 2·5 G 2·67 — 2·73. Case 52. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white. B. fusible. Soluble in water.

Found in crystals in the brine springs at Salinas d'Espartinas, near Madrid.

Glaserite.—*Sulphate of Potash, Arcanite.*—K O + S O^3. **prismatic.** H 2·5 — 3·0 G 2·689 — 2·709. *Frac.* conchoidal. Transparent. *Lus.* vitreous. *Col.* colourless, white, yellow, gray. *Str.* white. Brittle. B. fusible. Soluble in water.

Found on the lava of Vesuvius and in some springs.

Mascagnine.—*Sulphate of Ammonia.*—N H^4 O + S O^3. **prismatic.** H 2·0 — 2·5 G 1·68 — 1·78. *Frac.* imperfect conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, yellow. *Str.* white. Sectile. B. volatilizes. Soluble in water.

Found associated with sulphur, with volcanic productions, and in coal mines. Vesuvius, Etna, Solfatara, Lipari, Aveyron, Staffordshire.

Baryte.—*Sulphate of Barytes, Heavy Spar, Hepatite, Prismatic Hal-Baryta.*—Ba O + S O^3. **prismatic.**—H 3·0 — 3·5 G 4·35 — 4·59. Cases 52 and 53. *Frac.* conchoidal. Transparent or translucent. *Lus.* vitreous. *Col.* colourless, white, gray, blue, yellow, red. *Str.* white. Brittle. B. fusible with difficulty. Insoluble in hydrochloric acid.

Found in beds and veins in various formations. Westphalia, the Hartz, Saxony, Bohemia, Hungary, the Tyrol, Transylvania, France, Baden, Hessia, Cumberland, Surrey, Staffordshire, Derbyshire. *Hepatite or fetid baroselenite* is a variety of *baryte*, containing bitumen. Norway, The *Cawk* of Staffordshire and Derbyshire is an opaque, massive variety of baryte. The white varieties are ground and used as paint. All the salts of barytes but one are violent poisons. The nitrate of barytes is used for producing a green flame.

Celestine.—*Sulphate of Strontia, Prismatic Hal-Baryta.*—Sr O + S O^3. **prismatic.** H 3·0 — 3·5 G 3·85 — 4·0. Case 53. *Frac.* imperfect conchoidal. Transparent, translucent. Opaque. *Lus.* vitreous. *Col.* colourless, white, gray, blue, flesh-red. Brittle. B. fusible. Insoluble in hydrochloric acid.

Found in sulphur mines, limestones, metallic veins, and in fossils. Sicily, France, Hungary, Lake Erie, Jena, Bristol, Switzerland, Spain, Edinburgh. Distinguished from baryte by its specific gravity.

Gypsum.—*Sulphate of Lime, Selenite.*—Ca O + S O^3 + 2 H O. **oblique.** H 1·5 — 2·0 G 2·28 — 2·33. Case 54. *Frac.* flat, conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, red, yellow, blue, gray. *Str.* white. Sectile. B. fusible. Very slightly soluble in water and acids.

Found in new red sandstone, in older rocks, clay, in sulphur, and in fossils. Brunswick Hessia, Thuringia, the Tyrol, Switzerland, Paris, Oxford, Sicily, Spain, Siberia, Yorkshire, Cheshire, Derbyshire, Nottinghamshire, Scotland, the United States. The large blocks are wrought into alabaster figures and ornaments. Calcined and powdered it forms *plaster of Paris*. Distinguished by its softness from limestone.

Karstenite.—*Anhydrite, Anhydrous Sulphate of Lime, Cube Spar, Muriacite.*—Ca O + S O^3. **prismatic.** H 3·0 — 3·5 G 2·85 — 3·05. Case 54. *Frac.* imperfect conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, yellow, red, blue. *Str.* grayish-white. Brittle. B. fusible with difficulty. Slightly soluble in water and hydrochloric acid.

Found in beds and veins, and in clay. Styria, the Tyrol, Switzerland, Savoy, Italy, New York, the Hartz, Sweden.

Epsomite.—*Sulphate of Magnesia, Epsom Salt, Prismatic Bitter Salt.*—Mg O + S O^3 + 7 H O. **prismatic.** H 2·0 — 2·5 G 1·7 — 1·8. Case 55. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, red. *Str.* white. Taste bitter and saline. B. fusible. Soluble in water.

Found as an efflorescence and in mineral springs. Hungary, Bohemia, the Tyrol, Spain, South Africa, Milo, Sedlitz, Epsom, Chili. Is used for pharmaceutical purposes, but is generally obtained by manufacturing chemists from magnesian limestone, and other sources.

Halotrichite.—*Alunogen, Feather Alum, Hair Salt.*—(Al O^3 + S O^3) + 18 H O. H 2. Case 55. *Frac.* uneven. Translucent on the edges. *Lus.* dull. *Col.* white, gray, yellow. B. fusible. Soluble in water.

Found in alum shale, coal mines, and volcanic craters. Thuringia, Dresden, Bonn, Columbia, Bogota, Quito, Chili, Milo, Neapolitan Solfatara.

Polyhalite.—(K O + S O^3) + (Mg O + S O^3) + 2 (Ca O + S O^3) + 2 H O. **prismatic.** H 3·5 G 2·73 — 2·78. Case 55. *Frac.* uneven. Translucent. *Lus.* waxy. *Col.* red. *Str.* white. Brittle. B. fusible. Partially soluble in water.

Found in Styria, Austria, and Bavaria. Derives its name from *πολυς many*, and *αλς salt*, on account of the variety of its saline constituents.

Goslarite.—*Sulphate of Zinc, White Vitriol.*—Zn O + S O^3 + 7 H O. **prismatic.** H 2·0 — 2·5 G 1·9 — 2·1. Case 55. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous, *Col.* colourless, white, red, blue. *Str.* white. Brittle. B. infusible. Soluble in water.

Found in old mines. Sweden, the Hartz, Hungary, France, Spain, Holywell, Cornwall. Is not found in great abundance in nature, but is prepared artificially. Used in medicine and in dyeing. A permanent white colour. *Zinc white* is prepared from it.

Bieberite.—*Sulphate of Cobalt, Cobalt Vitriol.*—Co O + S O^3 + 7 H O. **oblique.** Case 55. *Frac.* uneven. Translucent, opaque. *Lus.* vitreous. *Col.* red. *Str.* reddish-white. Soluble in water.

Found in old mines. Bieber, Siegen, and Saltzburg.

Melanterite.—*Sulphate of Iron, Green Vitriol.*—Fe O + S O^3 + 7 H O. **oblique.**

H 2·0 G 1·8 — 1·9. Case 55. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* green, white. *Str.* white. Rather brittle. Soluble in water.

Found in old mines. Bavaria, Sweden, the Hartz, Saxony, Hungary. Used in dyeing and in the manfacture of sulphuric acid, ink, and Prussian blue.

Botryogen.—*Red Sulphate of Iron, Red Vitriol.*—**oblique.** H 2·0 — 2·5 G 2·039. Case 55. *Frac.* conchoidal. Translucent. *Lus.* vitreous. *Col.* red, yellow. *Str.* yellow. Sectile. B. infusible. Soluble partially in boiling water.

Found at Fahlun in Sweden. Derives its name from βοτρυς *a bunch of grapes*, because it frequently occurs in the form of globules with a crystalline surface.

Copiapite.—A hydrous sulphate of iron. Six-sided prisms. Translucent. *Lus.* pearly. *Col.* yellow.

Found at Coquimbo in Chili.

Coquimbite.—2 Fe O^3 + 3 S O^3 + 9 H O. **rhombohedral.** H 2·0 – 2·5 G 2·0 – 2·1. *Frac.* conchoidal, uneven. Translucent. *Col.* white, blue, green. Soluble in water.

Found in green felspar. Coquimbo.

Blue Vitriol.—*Sulphate of Copper, Cyanose.*—Cu O + S O^3 + 5 H O. **anorthic.** H 2·5 G 2·19 – 2·30. Case 55. *Frac.* conchoidal. Semi-transparent, translucent. *Lus.* vitreous. *Col.* blue. *Str.* white. Rather brittle. B. fusible. Soluble in water.

Found in mines, and in the water of mines. Sweden, Hungary, Cornwall, Anglesea, Wicklow, Seville, Cyprus, Siberia. After being purified, used in the manufactures, for dyeing and electrotyping.

Brochantite.—*Prismatic Dystome, Malachite, Krisuvigite.*—(Cu O + S O^3) + 3 (Cu O + H O). **prismatic.** H 3·5 – 4·0 G 3·87 – 3·9. Case 55. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* green. *Str.* green. B. infusible. Soluble in acids.

Found in Siberia, Hungary, Iceland, France.

Lettsomite.—*Velvet Copper Ore, Kupfersammterz.*—2 S O^3 + 6 Cu O + Al O^3 + 12 H O. Case 55. Capillary crystals. Translucent. *Lus.* pearly. *Col.* smalt blue.

Found with malachite at Moldawa, in the Banat, coating the cavities of an oxide of iron. It is extremely rare.

Linarite.—*Cupreous Sulphate of Lead, Diplogenic Lead Baryta.*—(Pb O + S O^3) + (Cu O + H O). **oblique.** H 2·5 – 3·0 G 5·3 – 5·43. Case 55. *Frac.* conchoidal. Feebly translucent. *Lus.* adamantine. *Col.* deep blue. *Str.* pale blue. Slightly brittle.

A rare mineral. Found at Leadhills, in Scotland, Spain, and Cumberland.

Johannite.—*Subsulphate of Uranium, Hemiprismatic Euchlore Salt.*—**oblique.** H 2·0 — 2·5 G 3·191. Case 55. *Frac.* imperfect conchoidal. Semi-transparent. *Lus.* vitreous. *Col.* green. *Str.* green. Sectile. Taste slightly bitter. Soluble in hydrochloric acid.

A very rare mineral. Found at Joachimsthal, in Bohemia.

Anglesite.—*Sulphate of Lead, Prismatic Lead Baryta, Lead Vitriol.*—Pb O + S O^3. **prismatic.** H 3·0 G 6·26 — 6·3. Case 55. *Frac.* conchoidal. Transparent, trans-

lucent. *Lus.* adamantine. *Col.* colourless, yellow, gray, brown, blue, green. *Str.* white. Brittle. B. fusible. Slightly soluble in nitric acid.

Produced by the decomposition of galena. Baden, Siegen, Silesia, the Hartz, Spain, Siberia, Massachusetts, Missouri, Anglesea, Cornwall, Scotland. It sometimes contains silver.

Lanarkite.—*Sulphato-Carbonate of Lead, Prismatoidal Lead Baryta.*— $(Pb\,O + S\,O^3) + (Pb\,O + C\,O^2)$. Thin plates. H 2·0 – 2·5 G 6·8 – 7·0. Case 55. Transparent. *Lus.* adamantine. *Col.* greenish or yellowish-white. *Str.* white. Sectile. B. fusible. Partially soluble in nitric acid.

Found at Leadhills in Scotland, and in Siberia.

Susannite.—$(Pb\,O + S\,O^3) + 3\,(Pb\,O + C\,O^2)$. **rhombohedral.** H 2·5 G 6·55. Case 55. Transparent, translucent. *Lus.* resinous, adamantine. *Col.* white, green, yellow, black. *Str.* white. B. fusible. Partially soluble in nitric acid.

Found at Leadhills in Scotland, and Moldawa, in the Banat.

Caledonite.—*Cupreous Sulphato-Carbonate of Lead, Paratomous Lead Baryta.*—**prismatic.** H 2·5 – 3·0 G 6·4. Case 55. *Frac.* uneven. Transparent, translucent. *Lus.* resinous. *Col.* blue. *Str.* blue. Rather brittle. B. fusible. Partially soluble in nitric acid.

A beautiful mineral. Found at Leadhills in Scotland.

Leadhillite.—*Sulphato-Tri-carbonate of Lead, Axotomous Lead Baryta.*—$(Pb\,O + S\,O^3) + 3\,(Pb\,O + C\,O^2)$. **prismatic.** H 2·5 G 6·26 – 6·43. Case 55. *Frac.* conchoidal. Transparent, translucent. *Lus.* resinous. *Col.* white, yellow, gray, green, brown. *Str.* white. Rather brittle. B. fusible. Partially soluble in nitric acid.

Found at Leadhills in Scotland.

Alum.—$(K\,O + S\,O^3) + (Al\,O^3 + 3\,S\,O^3) + 24\,H\,O$. **cubic.** H 2·0 – 2·5 G 1·9 — 2·0. Case 55. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* white. *Str.* white. Soluble in water.

Found as an efflorescence on aluminous rocks and lava. Lipari Islands, Sicily, St. Michael, Thuringia, Norway, Yorkshire. Used as a medicine, in dyeing, and in the manufacture of leather, paper, &c.

Soda Alum.—$(Na\,O + S\,O^3) + (Al\,O^3 + 3\,S\,O^3) + 24\,H\,O$. **cubic.** H 2·0 – 2·5 G 1·88. Case 55. *Frac.* conchoidal. Transparent. *Lus.* vitreous. *Col.* white. *Str.* white. Soluble in water.

Found in the Neapolitan Solfatara, Island of Milo, and Mendoza.

Ammonia Alum.—$(N\,H^3 + H\,O + S\,O^3) + (Al\,O^3 + 3\,S\,O^3) + 24\,H\,O$. **cubic.** H 2·0 – 2·5 G 1·753. Case 55. *Frac.* conchoidal. Translucent. *Lus.* vitreous. *Col.* colourless, grayish-white.

Found in clay and in a bed of brown coal. Thuringia, Bohemia.

Alunite.—*Alum Stone, Rhombohedral Alum Haloide.*—$(K\,O + S\,O^3) + 3\,(Al\,O^3 + S\,O^3) + 6\,H\,O$. **rhombohedral.** H 3·5 – 4·0 G 2·69 – 2·8. Transparent, semi-transparent. *Lus.* vitreous. *Col.* colourless, white, yellow, red, gray. *Str.* white. Brittle. B. infusible. Insoluble in hydrochloric acid.

Found at Tolfa, Tuscany, Hungary, France. The Hungarian varieties are so hard as to be used for mill-stones.

Websterite.—*Subsulphate of Alumina, Aluminite.*—$Al\,O^3 + S\,O^3 + 9H\,O$. H 1·0 G 1·6 — 1·7. Case 55. *Frac.* earthy. Opaque. *Lus.* dull. *Col.* white. *Str.* white. Sectile. B. infusible. Soluble in hydrochloric acid.

Found in botryoidal concretions imbedded in clay, at Halle, Paris, Newhaven.

Garnsdorfite.—*Pissophane.*—A hydrated sulphate of alumina and iron. Amorphous. H 1·5 — 2·0 G 1·922 — 1·981. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* green, brown. *Str.* grayish-white, pale-yellow. Brittle. Soluble in hydrochloric acid.

Found in the alum shale works. Garnsdorf in Thuringia, and Reichenbach in Saxony.

Voltaite.—**Cubic.** *Frac.* uneven. *Lus.* resinous. *Col.* black, inclining to brown and green. *Str.* grayish-green. Partially soluble in water.

Found in the Neapolitan Solfatara.

Hauyne.—*Dodecahedral Amphigene Spar, Noscan, Lapis Lazuli.*—**cubic.** H 5·5 — 6·0 G 2·25 — 2·5. Case 55. *Frac.* conchoidal. Transparent, opaque. *Lus.* vitreous. *Col.* black, brown, gray, blue. *Str.* light blue. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

The brown and gray variety, *noscan*, is found in volcanic rocks. Laach, in Prussia. The light blue and green, *hauyne*, in volcanic rocks and lava. Laach, the Rhine, France, Rome, Vesuvius. The deep blue, *lapis lazuli*, found mixed with calcite, mica, and pyrite. The Baikal Lake, China, Thibet, Tartary, South America. Valued as an ornamental stone; formerly used as the only source of the beautiful pigment called ultra-marine, which is now manufactured artificially.

Arsenite.—*Oxide of Arsenic, Octahedral Arsenic Acid, Arsenious Acid.*—$As\,O^3$. **cubic.** H 1·5 G 3·699. Case 56. *Frac.* conchoidal. Transparent, opaque. *Lus.* vitreous. *Col.* white. *Str.* white. B. volatilizes. Slightly soluble in water.

Probably produced by the decomposition of ores containing arsenic. Bohemia, Transylvania, Hanau, Alsace, the Hartz, the Pyrenees. Distinguished from pharmacolite, to which it is similar, by being slightly soluble in water. Artificially formed crystals of arsenic not only belong to the cubical system but also to the prismatic, being then isomorphous with valentinite. A very poisonous substance.

Pharmacolite.—*Arseniate of Lime, Hemiprismatic Euclase Haloide.*—$2\,Ca\,O + As\,O^5 + 6\,H\,O$. **oblique.** H 2·0 — 2·5 G 2·64 — 2·73. Case 56. Transparent, translucent. *Lus.* vitreous. *Col.* white, yellow. *Str.* white. Sectile, thin plates flexible. B. volatilizes. Soluble in nitric acid.

Found in Bohemia, Baden, the Hartz, Hessia, Thuringia, Alsace.

Kuhnite.—*Anhydrous Arseniate of Lime, Berzelite.*—$3\,R\,O + As\,O^5$, where R is Ca, Mg, and Mn. H 5·0 — 6·0 G 2·52. Case 56. *Frac.* uneven. *Lus.* waxy. *Col.* white, yellow. Brittle. B. infusible. Soluble in nitric acid.

Found in cleavable masses at Langbanshytta in Sweden.

Haidingerite.—*Diprismatic Euclase Haloide.*—$2\,Ca\,O + As\,O^5 + 4\,H\,O$. **prismatic.** H 2·0 — 2·5 G 2·848. Transparent, semi-transparent. *Lus.* vitreous. *Col.* white. *Str.* white. Sectile. B. fusible. Soluble in nitric acid.

A very rare mineral, supposed to have been found at Joachimsthal in Bohemia, formerly considered a variety of pharmacolite.

Roselite.—An arseniate of lime, magnesia, and cobalt. **prismatic.** H 3·0.

Frac. conchoidal. Translucent. *Lus.* vitreous. *Col.* red. *Str.* white. Soluble in hydrochloric acid.

An extremely rare mineral, found at Schneeberg.

Pharmacosiderite.—*Arseniate of Iron, Hexahedral Lirocone Malachite.*—$3\ Fe^2O^3 + 2\ As\ O^5 + 12\ H\ O$. **cubic.** H 2·5 G 2·9 — 3·0. Case 56. *Frac.* uneven. Semi-transparent, translucent on the edges. *Lus.* vitreous. *Col.* green, yellow, brown. *Str.* light yellow. Pyroelectric. B. fusible. Soluble in hydrochloric acid.

Found in veins of copper ores. Cornwall, France, Nassau, Saxony, United States.

Symplesite.—An arseniate of iron. **oblique.** H 2·5 G 2·957. *Frac.* even. Transparent, translucent. *Lus.* vitreous. *Col.* blue, green. *Str.* bluish-white. B. infusible.

Found at Klein Friesa, near Lobenstein.

Liroconite.—*Octahedral Arseniate of Copper, Lenticular Arseniate of Copper, Chalkophacit.*—**prismatic.** H 2·0 — 2·5 G 2·83 — 2·99. Case 56. *Frac.* imperfect conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* blue, green. *Str.* the same. B. fusible. Soluble in acids.

Found in Cornwall, Hungary, and Voigtland; very rare on the continent.

Olivenite.—*Rhight Prismatic Arseniate of Copper, Prismatic Olive Malachite.*—$(3\ Cu\ O + As\ O^5) + (Cu\ O + H\ O)$. **prismatic.** H 3·0 G 4·1 — 4·38. Case 56. *Frac.* conchoidal. Semi-transparent, opaque. *Lus.* vitreous. *Col.* green, brown. *Str.* olive-green. B. fusible. Soluble in nitric acid.

Found in Cornwall, Cumberland, the Tyrol, the Banat, Siberia, the Asturias, Chili.

Euchroite.—*Prismatic Emerald Malachite,*—$4\ Cu\ O + As\ O^5 + 7\ H\ O$. **prismatic.** H 3·5 — 4·0 G 3·35 — 3·45. Case 56. *Frac.* uneven. Transparent, translucent. *Lus.* vitreous. *Col.* pale green. Brittle. Soluble in nitric acid.

A very rare mineral, found in mica slate at Libethen in Hungary; named from ευχροια *beautiful colour.*

Scorodite.—*Martial Arseniate of Copper, Dystomic Fluor Haloide.*—$Fe^2O^3 + As\ O^5 + 4\ H\ O$. **prismatic.** H 3·5 — 4·0 G 3·18 — 3·30. Case 56. *Frac.* uneven. Semi-transparent, translucent on the edges. *Lus.* vitreous. *Col.* green, blue, brown. *Str.* white. Rather brittle. B. fusible. Soluble in hydrochloric acid.

Found in Saxony, Bohemia, Carinthia, France, Cornwall, Brazils, Columbia, Siberia.

Erinite.—*Dystomic Habroneme Malachite.*—$5\ Cu\ O + As\ O^5 + 2\ H\ O$. H 4·5 — 5·0 G 4·043. *Frac.* imperfect conchoidal. Translucent on the edges. *Lus.* dull. *Col.* green. *Str.* green. B. fusible. Soluble in nitric acid.

Found in the county of Limerick associated with arseniate of copper, named *erinite* on account of its characteristic emerald-green colour and its locality.

Cornwallite.—$5\ Cu\ O + As\ O^5 + 5\ H\ O$. Amorphous. H 4·5 G 4·166. *Frac.* conchoidal. *Col.* green. B. fusible.

Found with olivenite in Cornwall.

Klinoclase.—*Oblique Prismatic Arseniate of Copper, Strahlerz, Aphanese, Abichite.* $(3\ Cu\ O + As\ O^5) + 3\ (Cu\ O + H\ O)$. **oblique.** H 2·5 — 3·0 G 4·19 — 4·36. *Frac.* uneven. Translucent, opaque. *Lus.* vitreous. *Col.* green, dark blue. *Str.* verdigris-green. Rather brittle. B. fusible. Soluble in acids.

Found with liroconite. Cornwall, Erzgebirge. The crystals are extremely minute.

Tamarite.—*Rhomboidal Arseniate of Copper, Prismatic Copper Mica, Chalkophyllit.* —**rhombohedral.** H 2·0 G 2·435 — 2·659. *Frac.* conchoidal. Transparent, translucent. *Lus.* pearly or vitreous. *Col.* green. *Str.* green. Sectile. B. fusible. Soluble in acids.

Found in veins of copper ores in the mines of Cornwall.

Tyrolite.—*Kupferschaum, Prismatic Euchlore Mica.*—$(5\ Cu\ O + As\ O^5) + (Ca\ O + C\ O^2) + 10\ H\ O$. **prismatic.** H 1·0 — 2·0 G 3·02 — 3·098. Case 56. Translucent. *Lus.* pearly or vitreous. *Col.* green, blue. *Str.* the same. Very sectile. In thin leaves flexible. B. fusible. Soluble in hot nitric acid.

Found with ores of copper in fibrous groups of a delicate silky lustre. The Tyrol, Hungary, the Banat, Thuringia.

Konichalcite.—$2\ (R\ O + As\ O^5) + 3\ H\ O$, where R is Cu and Ca. H 4·0 — 4·5 G 4·123. *Frac.* splintery. Translucent on the edges. *Lus.* vitreous. *Col.* green. *Str.* green. Brittle.

In reniform masses supposed to have been found at Hinojosa in Andalusia.

Erythrine.—*Red Cobalt, Cobalt Bloom, Arseniate of Cobalt, Prismatic Cobalt Mica.*—$3\ Co\ O + As\ O^5 + 8\ H\ O$. **oblique.** H 1·5 — 2·0 G 2·9 — 3·1. Case 56. Transparent, translucent. *Col.* red, gray, green. *Str.* red. Sectile. In thin plates flexible. B. fusible. Soluble in hydrochloric acid.

A beautiful mineral, found in beds and veins with ores of cobalt. Saxony, Bohemia, Thuringia, Hessia, Baden, Dauphiné, the Pyrenees, Norway. When found in sufficient quantity, it is used in the manufacture of smalt. Distinguished from red antimony and red copper ore by yielding a blue glass with borax before the blowpipe.

Kottigite.—$Zn\ O + As\ O^5 + 8\ H\ O$. **oblique.** H 2·5 — 3·0 G 3·1. Translucent. *Lus.* silky. *Col.* red. *Str.* reddish-white. Soluble in acids.

Found with smaltine in the Daniel mine, Schneeberg.

Annabergite.—*Arseniate of Nickel, Nickel Bloom.*—$3\ Ni\ O + As\ O^5 + 8\ H\ O$. **oblique.** H 2·5 — 3·0 G 3·078 — 3·131. Case 56. *Col.* green. *Str.* greenish-white. B. fusible. Soluble in nitric acid.

Found in the Hartz, Hessia, Thuringia, Saxony, Bohemia, Dauphiné, Texas.

Vivianite.—*Phosphate of Iron, Blue Iron, Dichromatic Euclase Haloide, Anglarite, Mullicite, Prismatic Iron Mica.*—$3\ Fe\ O + P\ O^5 + 8\ H\ O$. **oblique.** H 1·5 — 2·0 G 2·6 — 2·7. Case 57. Transparent, translucent. *Lus.* pearly, vitreous. *Col.* green, blue. *Str.* white, becoming blue on exposure to air, powder of the mineral brown. Sectile. Thin plates flexible. B. fusible. Soluble in hydrochloric acid.

Found in mineral veins and lava, the earthy varieties in peat-bogs. Transylvania, Cornwall, Bavaria, New Jersey, Isle of France, Crimea, Shetland Islands, Isle of Man. Sometimes used as a pigment.

Dufrenite.—*Phosphate of Iron, Grüneisen Stein, Green Iron Earth, Alluaudite.*—**prismatic.** H 4·0 G 3·50 — 3·55. Case 57. Transparent, opaque. *Lus.* vitreous. *Col.* green. *Str.* light green. Brittle. B. fusible. Soluble in hydrochloric acid.

Found at Siegen, Hirschberg in Reuss, and Limoges in France.

Diadochite.—$Fe\ O^3 + 2\ P\ O^5 + 4\ (Fe\ O^3 + S\ O^3) + 32\ H\ O$. Amorphous. H 3·0 G 2·035 — 2·037. Case 57. *Frac.* conchoidal. Translucent, opaque. *Lus.* vitreous. *Col.* yellow, brown. *Str.* white. B. fusible on the edges.

Found in alum shale works near Gräfenthal and Saalfeld in Thuringia.

Zwiselite.—*Eisen Apatite, Iron Apatite.*—R Fl + (R O + P O^5), where R is Fe and Mn. **prismatic.** H 5·0 G 3·97. *Frac.* imperfect conchoidal. Translucent on the edges. *Lus.* resinous. *Col.* clove-brown. *Str.* grayish-white. B. fusible. Soluble in hot hydrochloric acid.

Found in crystalline masses at Zwisel in Bavaria.

Triplite.—*Phosphate of Manganese, Pitchy Iron Ore.*—(4 Fe O + P O^5) + (4 Mn O + P O^5). **prismatic.** H 5·0 — 5·5 G 3·6 — 3·8. Case 57. *Frac.* imperfect, conchoidal. Translucent on the edges, opaque. *Lus.* resinous. *Col.* brownish-black. *Str.* yellowish-gray. Brittle. B. fusible. Soluble in hydrochloric acid.

Found in crystalline masses in granite. France, United States.

Triphyline.—*Tetraphyline, Perowskine.*—(Li O + P O^5) + 6 (3 Fe O + P O^5). **oblique.** H 5·0 G 3·6. Case 57. *Frac.* imperfect conchoidal. Translucent on the edges. *Lus.* resinous *Col.* greenish-gray, spotted with blue. *Str.* grayish-white. B. fusible. Soluble in hydrochloric acid.

Found in granite accompanied by beryl. Rabenstein in Bavaria.

Delvauxine.—*Dehwauxite.*—2 Fe^2 O^3 + P O^5 + 24 H O. Amorphous. H 2·5 G 1·85. Case 57. *Frac.* conchoidal. Opaque, translucent on the edges. *Lus.* waxy. *Col.* black, brown, yellow. *Str.* light brown. B. fusible. Soluble in hydrochloric acid.

Found near Visé in Belgium.

Heterosite.—5 R O + P O^5 + 2 H O, where R is Fe and Mn. **oblique.** H 4·5 — 5·5 G 3·524. Case 57. *Frac.* uneven. Translucent on the edges, opaque. *Lus.* resinous, dull. *Col.* gray, blue, violet. *Str.* red. B. fusible. Soluble in hydrochloric acid.

Found in granite. Hureault, near Limoges in France.

Hureaulite.—*Huraulite.*—5 R O + P O^5 + 8 H O, where R is Mn or Fe. **oblique.** H 5·0 G 2·270. *Frac.* conchoidal. Transparent. *Lus.* vitreous. *Col.* yellow, red, brown. B. fusible. Soluble in hydrochloric acid.

Found in granite. Hureault, near Limoges in France.

Libethenite.—*Phosphate of Copper, Prismatic Olivenite, Diprismatic Olive Malachite.*—(3 Cu O + P O^5) + (Cu O + H O) **prismatic.** H 4·0 G 3·6 — 3·8. Case 57. *Frac.* conchoidal. Translucent on the edges. *Lus.* resinous. *Col.* olive-green. *Str.* olive-green. Brittle. B. fusible. Soluble in nitric acid.

Found in mica slate and with malachite. Hungary, the Rhine, Cornwall, the Ural, Chili.

Kryptolite.—*Kryptolith.*—A phosphate of oxide of cerium. G 4·6. Transparent. *Col.* pale yellow. Decomposed by warm hydrochloric acid.

Found in parallel acicular crystals, imbedded in massive apatite, from which it is separated by dissolving the apatite in dilute nitric acid. Arendal in Norway.

Thrombolite.—3 Cu O + 2 P O^5 + 6 H O. H 3·0 — 4·0 G 3·381 — 3·401. *Frac.* conchoidal. Opaque, translucent on the edges. *Lus.* vitreous. *Col.* green. *Str.* green. Brittle. B. fusible.

Found massive with malachite in limestone. Retzbanya in Hungary.

Lunnite.—*Hydrous Phosphate of Copper, Hemiprismatic Dystome Malachite, Phosphochalcite, pseudo malachite.*—$(3\ Cu\ O + P\ O^5) + 3\ (Cu\ O + H\ O)$. **oblique.** H 4·5 — 5·0 G 4·0 — 4·4. *Frac.* conchoidal. Semi-transparent, translucent on the edges. *Lus.* vitreous. *Col.* green. *Str.* green. Brittle. B. fusible. Soluble in nitric acid.

Found in grauwacke-slate. Bavaria, the Rhine, Reuss, the Ural.

Ehlite.—$5\ Cu\ O + P\ O^5 + 3\ H\ O$. H 1·5 — 2·0 G 3·8. *Lus.* pearly. *Col.* green. *Str.* pale green.

Found in reniform and botryoidal masses. The Rhine, the Ural. The *Kupferdiaspore*, a fibrous mineral from Libethen, is supposed to be *ehlite.*

Autunite.—*Yellow Uranite, Uran-mica, Phosphate of Uranium, Pyramidal Euchlore Malachite.*—$(Ca\ O + P\ O^5) + (2\ U^2\ O^3 + P\ O^5) + 8\ H\ O$. **pyramidal.** H 1·0 — 2·0 G 3·0 — 3·2. Case 57. Transparent, translucent. *Lus.* pearly, vitreous. *Col.* yellow, green. *Str* yellow. Sectile. B. fusible. Soluble in nitric acid.

A beautiful mineral, found in granite near Autun, and near Limoges in France. Distinguished from *green mica* by being soluble in nitric acid, and by the brittleness and inelasticity of its thin laminæ.

Torberite.—*Copper Uranite, Chalcolite, Pyramidal Euchlore Malachite, Green Uranite.*—$(Cu\ O + P\ O^5) + (2\ U^2\ O^3 + P\ O^5) + 8\ H\ O$. **pyramidal.** H 2·0 — 2·5 G 3·5 — 3·6. Case 57. Transparent, translucent. *Lus.* pearly and vitreous. *Col.* green. *Str.* green. Rather brittle. Soluble in nitric acid.

Found in slate and granite. Saxony, Bohemia, Bavaria, Cornwall, United States, Belgium.

Xenotime.—*Phosphate of Yttria, Phosphyttrite.*—$3\ Y\ O + P\ O^5$. **pyramidal.** H 4·5 — 5·0 G 4·39 — 4·557. Case 57. *Frac.* splintery. Translucent, translucent on the edges. *Lus.* resinous. *Col.* brown. *Str.* light brown. Brittle. B. infusible. Insoluble in acids.

A very scarce mineral, found in granite. Norway and Sweden.

Wavellite.—*Lasionite, Devonite, Phosphate of Alumina, Prismatic Wavelline Haloide.*—$3\ Al\ O^3 + 2\ P\ O^5 + 12\ H\ O$. **prismatic.** H 3·5 — 4·0 G 2·3 — 2·4. Case 57. *Frac.* imperfect conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, gray, green, yellow, brown. *Str.* white. Brittle. B. infusible. Soluble in acids.

Found in slate and granite. Devonshire, Cornwall, Ireland, Scotland, Bohemia, Saxony, Greenland, the Brazils, Pennsylvania.

Gibbsite.—*Hydrargyllite, Felsobanyite.*—$Al\ O^3 + P\ O^5 + 8\ H\ O$, mixed with $Al\ O^3 + 3\ H\ O$. Botryoidal masses. H 3·0 G 2·20 — 2·44. Case 19. Feebly translucent. *Lus.* dull. *Col.* greenish, grayish, yellowish-white. Brittle. B. infusible. Insoluble in hot hydrochloric acid.

In a mine of brown hematite. Richmond, Massachusetts.

Klaprothine.—*Lazulite, Voraulite. Azurite, Blue Spar.*—$2\ (R\ O + P\ O^5) + (Al\ O^3 + 3\ P\ O^5) + 6\ H\ O$, where R is Mg, Fe, and Ca. **oblique.** H 5·0 — 5·5 G 3·0 — 3·121 Case 57. *Frac.* uneven. Transparent, opaque. *Lus.* vitreous. *Col.* blue. *Str.* white. Very brittle. B. infusible. Not soluble in acids.

Found in crystals and massive. Saltzburg, Styria, Lower Austria, the Brazils.

Herderite.—*Prismatic Fluor Haloide.*—An anhydrous phosphate of lime and alumina and hydrofluoric acid. **prismatic.** H 5·0 G 2·985 – 2·99. *Frac.* conchoidal. Transparent. *Lus.* vitreous. *Col.* yellow, white. *Str.* white. Very brittle. B. fusible with difficulty. Soluble in hot hydrochloric acid.

Found very rarely in the tin mines of Ehrenfriedersdorf in Saxony. Its crystals resemble those of that variety of apatite which is called asparagus stone.

Amblygonite.—*Prismatic Amblygonite Spar.*—A phosphate of alumina. **prismatic.** H 6·0 G 3·045 – 3·11. Case 57. *Frac.* uneven. Semi-transparent, translucent. *Lus.* vitreous. *Col.* white, gray, green. *Str.* white. B. fusible. Soluble in sulphuric acid.

Found with tourmaline and topaz in granite. Saxony, Norway.

Turquoise.—*Calaite, Uncleavable Azure Spar.*—A hydrophosphate of alumina. **amorphous.** H 6·0 G 2·62 – 3·0. Case 57. *Frac.* conchoidal. Translucent on the edges, opaque. *Lus.* waxy. *Col.* blue, green. *Str.* greenish-white. Not very brittle. B. infusible. Soluble in hydrochloric acid.

Found in reniform and botryoidal masses. Persia, Thibet, Silesia, Lusatia, Saxony. Sold in the large towns of Persia in small masses, but in great quantities. Cut and polished, it is used for ornamental purposes; when its colour is good, it is greatly valued as a gem. The *occidental turquoise*, from Lower Languedoc, is a very different substance, being bone coloured with phosphate of iron.

Fischerite.—$2\,Al\,O^3 + P\,O^5 + 8\,H\,O$. H 5·0 G 2·46. Transparent. *Lus.* vitreous. *Col.* green. Soluble in sulphuric acid.

Found in small six-sided prisms. The Ural.

Kakokene.—A hydrophosphate of alumina and iron. G 2·336 – 3·38. Case 57. Translucent, opaque. *Lus.* pearly. *Col.* yellow. *Str.* yellow. B. fusible. Soluble in acids.

Found in Bohemia, Bavaria, and the United States. Derives its name from *κακος bad* and *ξενος a guest*, on account of the injurious effect of the phosphorus which it contains on the quality of the iron extracted from it as an ore.

Childrenite.—A phosphate of alumina and iron. **prismatic.** H 4·5 — 5·0. Case 57. *Frac.* uneven. Transparent. *Lus.* vitreous. *Col.* white, yellow, brown. *Str.* white.

Found on slate and quartz. Crinnis in Cornwall and Devonshire.

Wagnerite.—*Hemiprismatic Fluor Haloide.*—$Mg\,F + 3\,Mg\,O + P\,O^5$. **oblique.** H 5·0 — 5·5 G 2·98 — 3·13. Case 57. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* yellow, gray. *Str.* white. Brittle. B. fusible with difficulty. Soluble in hot nitric acid.

An extremely rare mineral, found in crystals with quartz in the crevices of a clay slate rock in the valley of Höllengraben in Saltzburg.

Monazite.—*Mengite, Edwardsite, Eremite.*—A phosphate of the oxides of cerium and lanthanium. **oblique.** H 5·5 G 4·8 – 5·0. Case 57. *Frac.* uneven. Semi-transparent, translucent on the edges. *Lus.* resinous. *Col.* brown, red. *Str.* reddish-yellow. B. fusible with difficulty on the edges. Decomposed by hydrochloric acid.

Found in a mixture of felspar, albite, and mica. Siberia and the United States.

Pyromorphite.—*Phosphate of Lead, Polysphærite, Miesite, Rhombohedral Lead*

Baryta.—(Pb O + Cl) + 3 (3 Pb O + P O^5). **rhombohedral.** H 3·5 — 4·0 G 6·9 — 7·1. Case 57 A. *Frac.* imperfect conchoidal. Semi-transparent. *Lus.* resinous. *Col.* green, brown, yellow, gray. Brittle. B. fusible. Soluble in nitric acid.

Found with galena. Bohemia, Saxony, Baden, the Hartz, France, Hungary, Cornwall, Cumberland, Durham, Yorkshire, Derbyshire, Scotland.

Mimetite.—*Arseniate of Lead, Brachytypous Lead Baryta, Arsenite, Hedyphane.*—Pb Cl + 3 (3 Pb O + As O^5). **rhombohedral.** H 3·5 — 4·0 G 7·18 — 7·28. Case 57 A. *Frac.* imperfect conchoidal. Translucent. *Lus.* resinous. *Col.* green, yellow. *Str.* white. Brittle. B. fusible. Soluble in nitric acid.

Found with galena. Saxony, Baden, Cornwall, Devonshire, Cumberland, France.

Apatite —*Phosphate of Lime, Talkapatite, Francolite, Moroxite, Asparagus Stone, Phosphorite, Rhombohedral Fluor Haloide.*—Ca Fl + 3 (3 Ca O + P O^5). **rhombohedral.** H 5·0 G 3·18 — 3·21 Case 57 B. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, blue, green, yellow, red, brown. *Str.* white. Brittle. B. fusible with difficulty. Soluble in hydrochloric acid.

Found in granite, gneiss, slate, marble, basalt, and in metallic veins. Spain, the Tyrol, Bohemia, Saxony, Cornwall, Devonshire, Cumberland, Norway, United States, Bavaria, France, the Ural. Named apatite by Werner, from *απαταω to deceive*, on account of the deception it so long caused to the older mineralogists.

Phosgenite.—*Murio Carbonate of Lead, Horn Lead, Corneous Lead.*—Pb Cl + Pb O + C O^2. **pyramidal.** H 3·0 G 6·0 — 6·2. Case 57 B. *Frac.* conchoidal. Transparent-translucent. *Lus.* adamantine. *Col.* colourless, white, gray, yellow, green, brown. *Str.* white. Brittle. B. fusible. Soluble in nitric acid.

A very rare mineral. Found in crystals and globular masses. Matlock in Derbyshire, Cornwall, Massachusetts.

Sodalite.—*Dodecahedral Amphigene Spar, Dodecahedral Zeolite.*—Na Cl + 3 (Na O + Si O^2) + 3 (Al O^3 + Si O^2). **cubic.** H 6·0 G 2·287 — 2·292. Case 57 B. *Frac.* conchoidal. Semi-transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, yellow, green, gray, blue. *Str.* white. B. fusible. Decomposed by hydrochloric acid, leaving a jelly of silica.

Found in lava, mica slate, and syenite. Sicily, Greenland, Siberia, Norway, United States.

Eudialyte.—*Rhombohedral Almandine Spar.*—2 (R O + Si O^2) + (Zr O + Si O^2) where R is Na, Ca, Fe, and Mn. **rhombohedral.** H 5·0 — 5·5 G 2·84 — 2·95. Case 57 B. *Frac.* conchoidal. Translucent on the edges. Opaque. *Lus.* vitreous. *Col.* red. *Str.* white. Slightly brittle. B. fusible. Partly decomposed by hydrochloric acid.

Found at Kangerdluarsuk, in West Greenland.

Pyrosmalite.—*Axotomous Perl Mica.*—15 (Fe O + Si O^2) + 15 (Mn O + Si O^2) + 3 (Fe^2 O^3 + H O) + Fe^2 Cl^3. **rhombohedral.** H 4·0 — 4·5 G 3·0 — 3·2. Case 57 B. *Frac.* uneven. Translucent, opaque. *Lus.* pearly or resinous. *Col.* brown, green. *Str.* lighter than the colour. B. fusible. Decomposed by hydrochloric acid.

A rare mineral. Found in attached and imbedded crystals. Sweden.

Fluor —*Fluate of Lime, Octahedral Fluor Haloide, Fluor Spar.*—Ca Fl. **cubic.**

H 4·0 G 3·017 — 3·188. Case 58. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, yellow, red, blue, green, black. *Str.* white, Brittle. B. infusible. Soluble in nitric and hydrochloric acids.

Found in veins in tertiary limestone, porphyry, and porphyritic greenstone. Saxony, Bohemia, Baden, Cornwall, Devonshire, Derbyshire, Cumberland, Northumberland, the Banat, Norway, Paris, Renfrewshire, Siberia, United States, Mexico, Vesuvius. The large crystalline masses of Derbyshire presenting a concentric arrangement of various colours, principally blue, is known by the name of *Blue John*. It is turned on the lathe into vases and other ornaments. Fluor is used as a flux for the metallic ores, hence its name from the Latin fluo *to flow*.

Fluellite.—*Fluoride of Aluminium.*—**prismatic.** Case 58. Translucent. *Col.* white.

A very rare mineral, found on granite, at Stenna Gwyn, in Cornwall.

Fluocerite.—*Neutral Fluate of Cerium.*—Ce F + Ce^2 F^3. **rhombohedral.** H 4·0 — 5·0 G 4·7. Case 58. *Frac.* uneven. Opaque. *Lus.* feeble. *Col.* red, yellow. *Str.* yellowish-white. B. infusible.

A very rare mineral, found in albite and quartz. Broddbo, near Fahlun, in Sweden.

Yttrocerite.—*Pyramidal Cerium Baryta.*—Ca F, Y F, Ce F. Case 58. *Frac.* uneven. Translucent, opaque. *Lus.* vitreous. *Col.* purple, blue, red, gray, white. *Str.* white. Brittle. B. infusible. Decomposed by sulphuric acid.

Found in quartz. Sweden, Massachusetts.

Chiolite.—3 Na F + 2 Al F^3. **pyramidal.** H 4·0 G 2·84 — 2·90. Case 58. Transparent, translucent. *Lus.* resinous. *Col.* colourless, white. B. fusible. Decomposed by sulphuric acid.

Found in granite. Miask, in Siberia.

Cryolite.—3 Na F + Al F^3. **prismatic.** H 2·5 — 3·0 G 2·953 — 2·963. Case 58. *Frac.* uneven. Semi-transparent, translucent. *Lus.* vitreous. *Col.* white, yellow, red, brown. *Str.* white. Brittle. B. fusible. Soluble in strong sulphuric acid.

Found in gneiss and granite. West Greenland, Siberia.

Chodnewite—2 Na F + Al F^3. H 4·0 G 3·0 — 3·08. Transparent, translucent. *Lus.* resinous. *Col.* colourless, white. B. fusible. Decomposed by sulphuric acid.

Found in granite. Miask, in Siberia.

Leucophane.—3 (Ca O + Si O^2) + (3 G O + 2 Si O^2) + Na F. **anorthic.** H 3·5 — 4·0 G 2·974. *Frac.* uneven. Transparent, translucent. *Lus.* vitreous. *Col.* yellow, green *Str.* white. Very tough. B. fusible.

Found imbedded in syenite, near Brevig, in Norway.

Topaz.—*Prismatic Topaz, Pycnite, Pyrophysalite.*—2 Al F^3 + 3 Si F^2 + 12 (Al O^3 + Si O^2). **prismatic.** H 8·0 G 3·4 — 3·6. Case 58 A. *Frac.* conchoidal. Transparent, translucent on the edges. *Lus.* vitreous. *Col.* colourless, white, yellow, red, blue, green. *Str.* white. B. infusible. By ignition, the yellow varieties become red, and the pale yellow colourless, without losing their transparency.

Found in granite, gneiss, and porphyry. Siberia, Moravia, Asia Minor, Saxony, the Brazils, Bohemia, Cornwall, Ireland, Scotland, Sweden. New South Wales. The purest

varieties from the Brazils, called the *Goutte d'eau*, when cut in facets, like the diamond, closely resemble it in lustre and brilliance. The topaz is used as an ornamental stone. The Brazilian topaz, which has been made red by exposure to heat, when polished, can be distinguished from the balcs ruby only by its becoming electric by friction.

Humite.—*Chondrodite, Hemiprismatic Chrysolite, Macherite, Brucite.*—3 (2 Mg O + Si O^3) + Mg Fl. **oblique**. H 6·5 G 3·10 – 3·20. Case 58 A. *Frac.* uneven. Transparent, translucent. *Lus.* vitreous. *Col.* yellow, brown, gray. *Str.* white. B. infusible. Soluble in hydrochloric acid, leaving a jelly of silica.

Found in limestone and dolomite. Finland. Sweden, United States, Vesuvius.

Salt.—*Muriate of Soda, Chloride of Sodium, Rock Salt.*—Na Cl. **cubic**. H 2·0 G 2·22. Case 59. *Frac.* conchoidal. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, yellow, red, green, blue. *Str.* white. Taste, saline. Rather brittle. B. fusible. Soluble in water.

Found widely disseminated, in thick beds and masses in various formations, and as an efflorescence covering large tracts of country. Hungary, Moldavia, Styria, the Tyrol, Bavaria, Wurtemberg, Switzerland, Spain, Cheshire, the Brazils, Mexico, Africa, Arabia. Used extensively for culinary purposes, agricultural and metallurgic operations, also in the manufacture of earthenware, soap, soda, &c.

Sylvine.—*Chloride of Potassium.*—K Cl. **cubic**. G 1·9 – 2·0. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white. Taste, salt, rather bitter. B. fuses and volatilizes. Soluble in water.

Found in crystals, and as an efflorescence. Vesuvius.

Sal Ammoniac.—*Muriate of Ammonia, Octahedral Ammonia Salt, Salmiak.*—N H^4 Cl. **cubic**. H 1·5 – 2·0 G 1·528. Case 59. Transparent, translucent. *Lus.* vitreous. *Col.* colourless, white, gray, yellow, brown, black. *Str.* white. Taste, saline. Very sectile. B. volatilizes without melting. Soluble in water.

Found in crystals and massive. Vesuvius, Etna, Solfatara, Lipari, Bourbon, Iceland, Bucharian Tartary, Himalaya Mountains, France, Scotland, Newcastle. Employed in medicine, metallurgic operations, and in tinning and soldering.

Cotunnite.—Pb Cl. **prismatic**. G 5·238. Case 59. Transparent. *Lus.* adamantine. *Col.* colourless, white. *Str.* white. B. fusible. Soluble in water.

Found in the crater of Vesuvius after the irruption of 1822.

Matlockite.—Pb Cl + Pb O. **pyramidal**. H 2·5 — 3·0 G 7·21. Case 59. *Frac.* uneven. Transparent, translucent. *Lus.* adamantine. *Col.* yellowish. B. fusible.

Found in old heaps in the Cromford level, near Matlock.

Mendipite.—*Kerasine, Peritomous Lead Baryta.*—Pb Cl + 2 Pb O. **prismatic**. H 2·5 – 3·0 G 7·0 — 7·1. Case 59. *Frac.* conchoidal. Translucent. *Lus.* adamantine. *Col.* white, yellow, red, blue. *Str.* white. B. fusible. Soluble in nitric acid.

Found with ores of lead. Mendip Hills, Somersetshire, Westphalia.

Remolinite.—*Muriate of Copper, Smaragdochalcit, Atacamite.*—Cu Cl + 3 (Cu O + H O). **prismatic**. H 3·0 – 3·5 G 3·69 – 3·71. Case 59. *Frac.* conchoidal. Semi-transparent, translucent on the edges. *Lus.* vitreous. *Col.* green. *Str.* green. Rather brittle. B. fusible. Soluble in acids.

Found in veins and as a volcanic product. Los Remoilinos, Guasko, Chili, Peru, Saxony, Vesuvius, Etna.

Connellite.—*Sulphato-chloride of Copper.* **rhombohedral.** *Lus.* vitreous. Translucent. *Col.* blue. B. fusible. Soluble in hydrochloric acid.

Found with arseniate of oxide of copper. Cornwall.

Percylite.—*A Hydrochloride of Lead and Copper.* **cubic**. H 2·5. Case 59. *Lus.* vitreous. *Col.* sky-blue. *Str.* the same. Soluble in nitric acid by boiling.

Found with gold in a matrix of quartz. La Sonora in Mexico.

Kerate.—*Muriate of Silver, Hexahedral Perl Kerate, Hornsilver.*—Ag Cl. **cubic.** H 1·0 — 1·5 G 5·55 — 5·60. Case 59. *Frac.* conchoidal. Transparent, translucent on the edges. *Lus.* waxy. *Col.* pearl-gray, blue, green, brown, yellowish-white. *Str.* shining. Malleable and sectile. B. fusible. Soluble in ammonia.

A rare mineral, found in veins with ores of silver. Mexico, Peru, Chili, Siberia, France, Cornwall, the Hartz. Derives its name from *κερας horn*, on account of its appearance.

Embolite.—2 Ag Br + 3 Ag Cl. **cubic**. H 2·0 G 5·789 — 5·806. *Frac.* hackly. *Lus.* adamantine. *Col.* yellow, green. Perfectly malleable.

Found in limestone. Copiapo in Chili.

Bromite.—*Bromide of Silver.* Ag Br. **cubic**. H 1·0 — 2·0 G 5·8 — 6·0. Case 59. *Lus.* bright. *Col.* green, yellow. *Str.* green. B. fusible. Soluble in warm concentrated ammonia.

Found with kerate. Mexico, Chili, Bretagne.

Iodite.—*Iodic Silver.*—Ag I. H 1·0 G 5·504. *Lus.* resinous. *Col.* yellow, green. *Str.* shining. B. fusible. Soluble in strong hydrochloric acid.

Found in serpentine and porphyry. Mexico, Chili, Spain.

Calomel.—*Muriate of Mercury, Pyramidal Perl Kerate, Horn Quicksilver.*—Hg^2 Cl **pyramidal**. H 1·5 G 6·4 — 6·5. Case 59. *Frac.* conchoidal. Translucent, translucent on the edges. *Lus.* adamantine. *Col.* gray, green, yellow, brown. *Str.* white. Sectile. B. volatilizes. Soluble in nitro-muriatic acid.

Found with mercury and cinnabar. Bohemia, the Palatinate, Carniola, Spain.

Coccinite.—*Ioduret of Mercury.*—*Lus.* adamantine. *Col.* red. Melts and sublimes easily.

This mineral is probably identical with the red crystals of Iodide of Mercury, Hg I, formed by cooling a saturated solution of Iodide of Mercury in an aqueous solution of Iodide of Mercury and Potassium. These crystals are *pyramidal;* when heated they sublime and form yellow crystals belonging to the prismatic system. The yellow crystals become red by being scratched or rubbed.

Mellite.—*Mellate of Alumina, Honey Stone, Pyramidal Melichrone Resin.*—Al O^3 + C^4 O^3 + 18 H O. **pyramidal**. H 2·0 — 2·5 G 1·5 — 1·6. Case 60. *Frac.* conchoidal. Transparent, translucent. *Lus.* resinous. *Col.* Honey-yellow, inclining to red or brown. *Str.* white. Sectile. Soluble in nitric acid.

Found in beds of brown coal. Thuringia, Bohemia, Moravia.

Humboltine.—*Oxalate of Iron, Oxalit.*—2 (Fe O + C^2 O^3) + 3 H O. H 2·0 G 2·15 — 2·25. Case 60. *Frac.* uneven. Opaque. *Lus.* waxy. *Col.* yellow. *Str.* yellow. Slightly sectile. Soluble in acids.

Found in a bed of brown coal. Bohemia, Hessia.

Whewellite.—*Oxalate of Lime.*—$Ca O + C^2 O^3 + H O$. **oblique.** H 2·5 — 3·0 G 1·833. *Frac.* conchoidal. Transparent, opaque. *Lus.* vitreous, colourless. *Str.* white. Very brittle.

Found with calcite. Hungary.

Struvite.—*Guanite.*—$(2 Mg O + P O^5) + N H^3 + 13 H O$. **prismatic.** H 1·5 — 2·0 G 1·66 — 1·75. Case 60A. *Frac.* conchoidal. Transparent, semi-transparent. *Lus.* vitreous. *Col.* colourless, yellow, brown. *Str.* white. B. fusible. Soluble in hydrochloric acid.

Found in crystals in 1815, when digging the foundation of the new church of St. Nicholas, Hamburgh, having been produced by the decomposition of animal matter; it has also been discovered in guano from the coast of Africa.

Amber.—*Bernstein, Succinite.*—$C^{10} H^8 O$. Amorphous. H 2·0 — 2·5 G 1·0 — 1·1. Case 60. Transparent, translucent. *Lus.* waxy. *Col.* yellow, red, brown, white. *Str.* yellowish-white. Slightly brittle.

Found in rounded masses and disseminated, occurs principally in the tertiary coal formations. Sicily, Prussia, Pomerania, Holstein, Courland, Livonia, Greenland, China, France. Italy, Spain, England, Ireland. It frequently contains insects which are now extinct. Used for ornamental purposes, and also in the manufacture of varnishes.

Copaline —*Fossil Copal, Highgate Resin.*—Amorphous. H 2·5 G 1·046. Case 60. *Frac.* conchoidal. Semi-transparent, translucent. *Lus.* waxy. *Col.* yellow, brown. Brittle. Slightly soluble in ether.

Found in blue clay. Highgate near London, and in the East Indies.

Retinasphalt.—*Retinite.*—Amorphous. H 1·0 — 2·0 G 1·05 — 1·20. Case 60. *Frac.* conchoidal. Semi-transparent, opaque. *Col.* yellow, brown, gray. *Str.* yellowish-brown. Brittle.

Found in brown coal, stone coal and peat. Halle, Vogelsgebirge, Devonshire, Maryland, Bohemia, Osnabrück.

Naphtha.—*Earth Oil, Bitumen.* Liquid. G 0·7 — 0·8. Case 60. Transparent, translucent. *Col.* colourless, yellow, brown. Unctuous to the touch. Smell aromatic and bituminous. Soluble in pure alcohol.

Found oozing out of clefts in rocks or the ground. Italy, the Alps, Pyrenees, United States, Persia, East Indies, China, Baku. When exposed to the air becomes thick and at last solid. *Petroleum*, *Elaterite*, and *Asphaltum*, are supposed to be naphtha thus altered.

Petroleum, found in Hanover, Brunswick, Alsace, Auvergne, Barbadoes, Trinidad, Lancashire, Coalbrookdale, Edinburgh, Ava.

Elaterite, found in Derbyshire, France, and Connecticut.

Asphaltum, found in Hanover, Soult, the Rhone, the Dead Sea, Cornwall, Shropshire, East Lothian.

Scheererite.—$C H^2$. **oblique.** Soft. G 1·0 — 1·2. Case 60. *Frac.* conchoidal. Transparent, translucent. *Lus.* resinous. *Col.* white, gray, yellow, green. *Str.* white. Brittle. Unctuous to the touch. Soluble in nitric acid.

Found in brown coal. St. Gallen, Westerwald.

Konleinite.—*Konlite.*—$C^2 H$. G 0·88. *Col.* white.

Found in crystalline plates and grains, in brown coal and in a peat bog. Switzerland, Bavaria.

Fichtelite.—A hydrocarbon. Transparent. *Lus.* pearly, colourless. Unctuous to the touch. Without taste or smell. Soluble in ether.

Found in acicular crystals, between the yearly rings of pine stems in a bed of turf. Redwitz, near the Fichtelgebirge.

Hartite.—A hydrocarbon. H 1·0 G 1·046. Case 60. *Frac.* conchoidal. Translucent. *Lus.* fatty, feeble. *Col.* white. Not flexible. Sectile. Soluble in ether.

Found in brown coal. Oberhart in Austria.

Ozokerite.—C H. H 1·0 G 0·94 — 0·97. *Frac.* conchoidal. *Lus.* waxy. Translucent on the edges. *Col.* green, brown, yellow, red. *Str.* yellowish-white. Sectile, tough and flexible. Soluble in oil of turpentine.

Found in Moldavia, Austria, Newcastle.

Hatchettine.—C H. H 1·0 G 0·6078. Case 60. Translucent, nearly opaque. *Lus.* pearly. *Col.* yellow. Partially soluble in ether.

Found in masses resembling wax or train oil, in the coal formations of England and Scotland.

Middletonite.—G 1·6. Thin fragments, transparent. *Lus.* resinous. *Col.* brown. *Str.* light brown. Soluble in concentrated sulphuric acid.

Found in small rounded masses between layers of coal. Leeds, Newcastle.

Psathyrite.—*Hartin.*—G 1·115. *Col.* white. Soluble in petroleum.

Found in masses resembling train oil in brown coal. Oberhart in Austria.

Guyaquillite.—Amorphous, soft. G 1·092. Opaque. *Col.* bright yellow. Soluble in alcohol.

Found at Guyaquil in South America. A substance found in the Irish bogs, and called *bog butter*, seems to be allied to guyaquillite.

Berengelite.—Amorphous. *Frac.* conchoidal. *Lus.* resinous. *Col.* dark brown. *Str.* yellow. Taste, bitter. Soluble in ether.

Found in large masses in the province of St. Juan de Berengela in South America.

Walchowite.—Amorphous. H 1·5 — 2·0 G 1·035 — 1·069. *Frac.* conchoidal. Translucent. Translucent on the edges. *Lus.* fatty. *Col.* yellow, brown. *Str.* yellowish-white. Brittle. Soluble in sulphuric acid.

Found in brown coal. Walchow in Moravia.

Ixolyte.—Amorphous. H 1·0 G 1·008. Case 60. *Frac.* conchoidal. *Lus.* resinous. *Col.* red. *Str.* yellow. Sectile. Smell, aromatic.

Found in brown coal. Oberhart in Austria.

Piauzite.—H 1·5 G 1·220. *Frac.* imperfect conchoidal. Translucent on the thinnest edges. *Col.* blackish-brown. *Str.* yellowish-brown. Sectile.

Found in a bed of brown coal, near Piauze in Carniola.

Anthracite. H 2·0 — 2·5 G 1·3 — 1·75. Case 60. *Frac.* conchoidal. *Lus.* vitreous. *Col.* black. *Str.* black. Brittle.

Found in the Alps, Pyrenees, France, Pennsylvania, Massachusetts, Bohemia, Silesia, Saxony, Hessia, Staffordshire, Brecknockshire, Carmarthenshire, Pembrokeshire, Scotland, Ireland. Used as a fuel for furnaces.

Black Coal.—*Bituminous coal.* H 2·0 — 2·5. Case 60. *Frac.* conchoidal. *Lus.* waxy. *Col.* black. *Str.* black. Slightly sectile. Brittle.

Found in England, Germany, Bohemia, Moravia, Belgium, France, North America, China, Japan, Australia. Most valuable as a fuel. Upwards of 50,000,000 tons are obtained from the coal fields of England annually.

Brown Coal.—*Lignite.* H 1·0 — 2·5 G 0·5 — 1·5. Case 60. *Frac.* conchoidal. *Lus.* waxy. *Col.* brown, black. *Str.* brown.

Found in Germany, Switzerland, Hungary, Italy, Greece, Iceland, Greenland, Devonshire, Sussex, Scotland, Faroe Isles, Ireland.

WALTER MITCHELL, M.A.
J. TENNANT, F.G.S.

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